AD-A058 738 WYLE LABS HUNTSVILLE ALA F/G 6/7

PERSONAL FLOTATION DEVICES RESEARCH. VOLUME 2. RESEARCH REPORT.(U)

JAN 78 T DOLL, M PFAUTH, J GLEASON, S COHEN DOT-CG-42333-A

UNCLASSIFIED MSR-78-1-VOL-2 USCG-D-41-78-VOL-2 NL

1 OF 6

AD
A058738

OF 6

8738

Report No. CG-D-41-78

LEVEL III

A058739 VOL II

PERSONAL FLOTATION DEVICES RESEARCH - PHASE II

VOLUME 2 - RESEARCH REPORT

Wyle Laboratories
7800 Governors Drive, West
Huntsville, AL 35807

JANUARY 1978

FINAL REPORT

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report do not necessarilv reflect the official view or policy of the Coast Guard; and they do not constitute a standard, specification, or regulation.

This report, or portions thereof may not be used for advertising or sales promotion purposes. Citation of trade names and manufacturers does not constitute endorsement or approval of such products.

(19)

Technical Report Documentation Page

1. Report No.
(18) USCG D-41-78-Vol-2

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
(6) PERSONAL FLOTATION DEVICES RESEARCH - PHASE II
VOLUME 2, ~~of 3 VOLUMES:~~ RESEARCH REPORT

5. Report Date
(11) JANUARY 1978

6. Performing Organization Code
D.O. DOT-CG-70529-A

7. Author(s)
(10) T. DOLL, M. PFAUTH, J. GLEASON, S. COHEN, C. STIEHL, R. GIUNTINI, AND B. HAYES

8. Performing Organization Report No.
(14) MSR-78-1-Vol-2

9. Performing Organization Name and Address
Wyle Laboratories
P. O. Box 1008
Huntsville, AL 35807

(12) 520p.

10. Work Unit No. (TRAIS)
3503.5.2

11. Contract or Grant No.
(15) DOT-CG-42333-A

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, D. C. 20590

13. Type of Report and Period Covered
(9) FINAL REPORT,
October 1976-January 1978
on Phase 2,

14. Sponsoring Agency Code
G-DSA

15. Supplementary Notes
The U.S. Coast Guard's Research and Development Technical Representative for the work performed herein were CAPT C. NIEDERMAN, LTJG S. WIKER and T. Sheehan.

16. Abstract
Research on personal flotation devices (PFDs) is reported in three volumes. Volume 1 summarizes the research and presents a Proposed Technical Approach for development of performance-based PFD evaluation procedures. Volume II is the technical report. Volume III contains appendices. The Life-Saving Index (LSI) System provides a quantitative measure of the life-saving capability of PFDs called the Life-Saving Index (LSI). The LSI predicts the life-saving performance of the candidate PFD and makes it possible to compare diverse PFDs including inflatables, hybrids, and inherently buoyant devices. In one of two studies of PFD wearability/accessibility, nearly 2500 boaters were observed in recreational boating activities. In Study II, 67 different kinds of PFDs representing the major varieties available world-wide were distributed to recreational boaters for use and evaluation. Indices of PFD wearability and accessibility were developed, based upon evaluations and PFD use behavior. One approach to PFD effectiveness used the center and distribution of buoyancy to predict the effectiveness of PFDs on human subjects. A second approach employed an anthropomorphic dummy to simulate human buoyancy characteristics. A PFD effectiveness evaluation procedure using human body simulators is recommended. Reliability research centered on the development of an accelerated aging method which simulates the aging of PFDs in the recreational boating environment. Controlled experiments were performed to determine the individual and combined effects of environmental stressors on PFDs. Test procedures and a reliability model are presented. Further development of the Accident Recovery Model (ARM) is reported, including expansion of the data base. ARM provides estimates of accident recovery parameters and benefits. Alternative plans for implementation of the LSI System and cost/benefit analyses are presented.

17. Key Words
Life-Saving Index, Personal Flotation Devices, Wearability, Accessibility, Effectiveness, Reliability, Accident Recovery Model, Accelerated Aging, Flotation Dummy, Life Jackets, Life Preservers

18. Distribution Statement
Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	529	

Form DOT F 1700.7 (8-72)

405 959

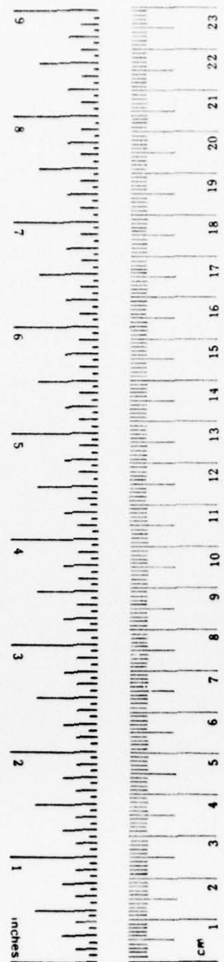
78 09 11 027

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

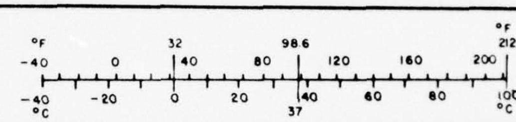
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



VOLUME 2 - RESEARCH REPORT

TABLE OF CONTENTS

(MAJOR SECTIONS)

TABLE OF CONTENTS (concluded)

SECTION I
INTRODUCTION/SUMMARY

This volume of the Phase II Research on Personal Flotation Devices (PFDs) presents the main body of a three-volume report. Volume I is an Executive Summary and Proposed Approach or Plan for Phase III and IV (future) research. This volume (II) presents the details of work performed while Volume III contains all Appendices to Volume II.

Within this volume are seven sections which present the results of two years of research on the life-saving capability of present personal flotation devices. Section II introduces the Life-Saving Index concept (LSI) and explains the terminology and mathematical formulation of the Index which is designed to indicate the life-saving capability of a PFD. Sections III through V present the work done on the three main components of the LSI: WEARABILITY, RELIABILITY, and EFFECTIVENESS. Section VI explains how accident data has been analyzed and accidents modeled by use of the Accident Recovery Model. Also presented are estimates of the effectiveness of present PFDs in saving lives.

Finally, Section VII introduces the Life-Saving Index (LSI) System and describes a preliminary recommendation for a means of using the research reported herein within the Coast Guard's PFD approval/certification process such that a wider range of PFD concepts might be approved. Each section in this volume was summarized by a corresponding section in Volume I. The Volume I summaries were designed for management level consumption. A more detailed summary appears as the first portion of each section of this volume. The Appendices to the sections in this volume (Volume III) are numbered corresponding to the section numbering in this volume (i.e., the first appendix to Section VII is contained in Volume III and is numbered VII-A). References are listed at the end of each section of this volume.

Each section summary is presented below to provide the casual reader with an overview of the work documented by this research report. These summaries are also presented within the appropriate sections, preceded by detailed tables of contents and lists of figures and tables.

SECTION II - THE LIFE-SAVING INDEX (LSI)

Coast Guard statistics (Reference 1) show that between 1400 and 1800 people die in recreational boating* accidents each year. The same source also reports that approximately 90% of these deaths are due to drowning. In order to reduce the number of drownings, the Coast Guard has promulgated PFD standards and carriage requirements and undertaken research concerning the use and functioning of PFDs. The present report represents the second phase of this research undertaken by Wyle Laboratories. Previous work by other contractors indicated that it might be beneficial to develop a "life-saving index" (LSI). The LSI is a quantitative estimate of a PFD's life-saving capability.

This section reviews the further development of the LSI undertaken by Wyle Laboratories to provide the Coast Guard with a more flexible and effective regulatory mechanism for evaluating PFDs.

The following equation represents the life-saving capability of an individual PFD. It is presumed that the physical effectiveness of a PFD depends upon whether it is worn or held, hence two types of effectiveness appear in the equation. The equation also provides for the possibility that an accessible PFD may be donned after the victim of an accident enters the water.

$$\boxed{LSI = [I_W \cdot E_W + I_{AC} \cdot P_D \cdot E_W + I_{AC} \cdot P_H \cdot E_H] \cdot R}$$

where

I_W = The probability that the PFD is worn immediately prior to entering the water in an accident (the wearability index).

I_{AC} = The probability that the PFD is accessible to a boater but not worn initially upon entering the water in an accident (accessibility index).

P_D = The probability that the accident victim dons the PFD in the water.

---

*Whenever the term "boat" appears in the balance of this report, it means recreational watercraft subject to regulation through the Federal Boat Safety Act of 1971.

P_H = The probability that the accident victim holds or lies upon the PFD in the water.

E_W = The probability that the PFD maintains or turns the wearer in the water to a position with a minimum required freeboard to the lower respiratory passage within a specified time limit (effectiveness when worn).

E_H = The probability that the PFD provides a minimum required freeboard to the lower respiratory passage for a relaxed person holding or lying upon the device in the water (effectiveness when held).

R = The probability that a PFD will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended (reliability).

In the proposed Life-Saving Index System, the LSI serves as the primary tool for evaluating PFDs which are candidates for certification or approval (see Figure II-3). The performance parameters of the PFD (wearability, accessibility, effectiveness, and reliability) would be measured as detailed in Sections III through V of this report. The LSI can then be computed and compared to a minimum LSI established by the Coast Guard. Only those candidate PFDs which meet or exceed the minimum LSI would be certified or approved. In addition to establishing a minimum LSI, the Coast Guard may deem it desirable to establish minimums for the indices of effectiveness and reliability.

SECTION III - DEVELOPMENT OF A TEST METHOD AND MODEL FOR PFD WEARABILITY AND ACCESSIBILITY

The primary objectives of wearability/accessibility research were to: a) determine what factors influence the wearability and accessibility of PFDs, and b) to develop test methods and models for evaluating PFD wearability and accessibility.

Section 3.0 describes an observational study of PFD accessibility and wear. The goal of this study was to obtain accurate estimates of PFD wear and accessibility in recreational boating throughout the United States. The study was designed in such a way that it eliminates or minimizes several serious methodological flaws in previous research. The results show that the overall percentage of recreational boaters wearing PFDs is 7.1%. The study also shows that PFD wear and accessibility depend upon the boater's activity, boat size, the wearer's sex and age, as well as the properties of the PFD.

A second set of studies (see Section 4.0) was undertaken to develop methods for predicting the wearability and accessibility of PFDs in recreational boating. Sixty-seven different models of PFDs encompassing most of the major varieties available world-wide were distributed to recreational boaters for their use and evaluation. Thirty-six participants in that study produced a data base of 185 PFD evaluations. Each evaluation encompassed PFD properties (including appearance, comfort, compatibility with the boater's activities, image, perceived effectiveness and reliability, wearability, and accessibility); boater demographics, activities, and attitudes; and situational variables (boat type, boat length, weather conditions, etc.). Multivariate statistical techniques, including factor analysis, canonical correlation analysis, and multiple linear regression were used to develop indices

of PFD wearability and accessibility. It is demonstrated that these indices are valid and reliable predictors of PFD wear and accessibility. The wearability index matches closely the wear rates obtained by observing boaters in the field. An accuracy of prediction of $\pm$ 5% for both wearability and accessibility can be achieved using a panel of about 12 boaters, each evaluating the PFD on two outings.

The final section of this chapter describes test procedures for the evaluation of PFD wearability and accessibility based on the results of the above study. This section also offers some recommendations for further research and development.

SECTION IV - PHYSICAL EFFECTIVENESS

The Life Saving Index System combines the major components of wearability, effectiveness, and reliability into a model which can be used to evaluate the life saving capability of PFDs.

The purpose of this section is to provide a methodology for use in evaluating the physical effectiveness of a particular PFD design. Two methods were investigated for predicting PFD effectiveness: 1) measurement of general PFD properties, and 2) tests of PFD using an anthropomorphic dummy. The results of the measurement for PFD properties and the results using the anthropomorphic dummy are compared to the human subject test results to find the best method for predicting PFD effectiveness.

Human subject testing of various PFDs for physical effectiveness parameters was performed. The results of this study produced information on the effectiveness of various PFDs on a wide range of subjects. The study permits a comparison of representative inherently buoyant, inflatable, and hybrid devices on effectiveness parameters. The results of this study have been used to develop and test alternative methods for predicting PFD effectiveness parameters.

PFD properties were measured and compared to the performance of each PFD in the human subject experiments. The centers of buoyancy of PFDs were measured using a one-ring and three-ring system. Measurements were also made of total PFD buoyancy and buoyancy forward of the centerline. An analysis was made of the measurements to determine the forces acting in various designs. One of the important results is that the Turning Moment Index, which is defined by the total buoyancy for each PFD and its center of buoyancy, correlates well with the performance of PFDs with human subjects in the Head Forward Moving Test. However, PFD properties did not adequately predict the performance of PFDs with human subjects in other tests.

Effectiveness testing using an anthropomorphic dummy is discussed. The details of the test methods are enumerated along with emphasis on precautions and limitations.

The predicted effectiveness using the Dummy Test Method is compared with the performance of each PFD in the human subject experiments. The dummy is shown to adequately predict the effectiveness of PFDs for providing an adequate turning moment and maintaining freeboard.

A recommended effectiveness test procedure, using the dummy, concludes this section.

SECTION V - DEVELOPMENT OF RELIABILITY TEST METHODOLOGY FOR PFDS

The Life Saving Index System combines the major components of wearability, effectiveness, and reliability into a model which can be used to evaluate the life saving capability of PFDs and evaluate trade-offs in the three major components.

The reason that reliability is included in the model is that it was theorized that if an advanced conceptual PFD design such as a PFD whose buoyancy was the result of an inflated chamber, hereafter defined as an inflatable PFD, could be developed, that the size, bulkiness and appearance would be such that more recreational boaters would be inclined to wear this style PFD. It was further theorized that this increased wear rate could save many lives. It was argued, however, that these new inflatable PFDs may be less reliable than the existing USCG approved PFD designs whose buoyancy is a result of being manufactured with components which are naturally buoyant, hereafter defined as an inherently buoyant PFD.

It was necessary, therefore to quantify the reliability so that the LSI System could evaluate these theories and arguments to determine whether or not potential lives could be saved by the introduction of new advanced concepts.

Reliability is defined as the probability of a PFD to perform its function of providing adequate buoyancy without failure under given recreational boating conditions for a given period of time. It is recognized from this definition that even an inherently buoyant PFD would become unreliable if it failed to provide adequate buoyancy for the wearer for the entire duration for which he may need it. Reliability, therefore, is concerned with the functioning of the PFD for its useful life in the environment for which it was intended. It places new requirements on approval standards to be able to adequately evaluate a PFD for its useful life in its intended environment.

These problems necessitated that a methodology be developed which could evaluate a PFD when it was subjected to an environment indicative of recreational boating and that a figure of merit be given based upon how well the PFD performs.

The first part of this section addresses the development of a test sequence which simulates the recreational boating environment. This is done using currently USCG approved inherently buoyant PFDs since PFDs which have been used by recreational boaters can be compared objectively to PFDs which are subjected to a simulated recreational boating environment, and this simulated environment is adjusted until it accurately simulates the recreational boating environment. This use of artificial environments to simulate real world environmental stresses necessitates careful analysis of failure modes and mechanisms to assure that the environment is adequately simulated.

The second part of this section is the reliability analysis of inflatable and hybrid PFDs. The analysis of these styles requires that the simulated environment determined for certain inherently buoyant PFDs be supplemented with environmental factors which are uniquely detrimental to the reliability of inflatable PFDs.

A comparison is made of the existing specifications on inflatable PFDs, which include Australian, British, Canadian, Federal Aviation Administration and Navy specifications. These specifications generally limit themselves to testing of the design characteristics and do not provide for an assessment of the reliability. Therefore, a Reliability Test Plan had to be developed which would test the susceptibility of inflatables to extremes of the recreational boating environment. The results of inflatable PFDs subjected to this test plan showed that an Accelerated Testing Technique is feasible for testing inflatable PFDs, that latent failure modes, which were either manufacturing or design problems, were transformed into detectable failures by the environmental stresses, and that the state-of-the-art for selected types of inflatables is such that these types of inflatables are reliable. The problem of maintainability was not studied in this research.

Therefore, an Accelerated Aging Test Sequence was developed which is applicable to inherently buoyant, inflatable and hybrid PFDs. The test results of PFDs subjected to the Accelerated Test Sequence are then inserted into a Reliability Prediction Model to arrive at a Reliability Index which can be used to compare styles, safety features and manufacturers.

Also included in this section are estimates of the reliability of those devices tested, an analysis of the failure modes and effects, which is used to recommend actions to minimize these failure modes, and an analysis of inflation systems.

SECTION VI - THE ACCIDENT RECOVERY MODEL (ARM)

The Accident Recovery Model (ARM) has been developed as an analysis tool, with related techniques and procedures that organize and summarize accident data so that the role of personal flotation devices in saving lives can be evaluated and the impacts (in terms of reducing fatalities) of existing the proposed regulatory and educational programs can be assessed. The discussions in this section demonstrate how ARM has fulfilled its dual purpose.

ARM was developed as a versatile and general data analysis model, in response to the complex and interactive nature of the processes by which boating accident victims live and die. The model is empirical, and represents an organized and structured data base. The development of ARM was an iterative process, requiring repeated development of parts of the model, and testing by processing accident data. In order to accomplish the desired versatility and generality of ARM, the model was designed to encompass a large number of variables in the accident data. A detailed sampling and weighting plan was devised for the selection of the accidents to be processed, and the projection of these data to represent the entire data base of the Coast Guard for reported recreational boating accidents. The boating accident reports in the ARM sample were each coded independently by two analysts, and the codings were verified by computer and a third analyst (the verifier). About 10% of the verified codings were reviewed by senior project personnel for accuracy. Thus, the data were sampled, coded, verified, and weighted in order to accurately mirror the recreational boating accidents for an "average" year.

The basic results reported in this section indicate that the ARM data base is representative of the Coast Guard's data. The thorough examination of those results in the text, variable by variable, points out the need for more detailed analysis and statistical techniques in order to examine several variables simultaneously. The ARM data are compared to Coast Guard data for geographical distribution, time of day, month, and other variables in the pages that follow, in order to establish the representativeness of the ARM data. Additional analyses are generated which illustrate the influences of boat parameters, environmental factors, and people's behavior on the probability that an individual survives his or her accident. Several of these variables display similar tendencies in the data, indicating the need for multiple variable analyses.

The basic results also indicate problem areas in recreational boating. These were identified by the low probabilities of recovery corresponding to victims in parts of ARM. For example, it was found that certain boat types (canoes, kayaks, open manual boats, and "other" boats) are associated with a lower chance of survival in an accident than others (powerboats, cabin cruisers, houseboats, and sail boats).* For "type of power," all types of propulsion were associated

*Based on analyses of reportable accidents.

with comparable probabilities of recovery except "manual," which had a lower chance of survival associated with it. Such results abound in the presentation of the ARM data.

The detailed analyses revealed significant interrelationships between variables and their effects on a victim's chances for survival. In particular, it was found that PFD wear was highly associated with severe conditions on other variables (water conditions, victim's circumstances, and others). For example, a victim who wore a PFD was much more likely to have been in rough water than a victim who didn't wear a PFD. The victim who didn't wear, was much more likely to have been in calm water. This means that variables such as water conditions can introduce biases in the comparisons (overall) of PFD wearers to non-wearers. A solution to this problem is to include an analysis of variables other than those of direct interest to a particular estimate or evaluation for their possible biasing effects on that estimate or evaluation. Examples of these "multi-state" solutions are included in this section of the report.

It is shown that ARM can be used to measure the relative importance of PFD properties such as self-actuation of inflatables, the ability to turn an unconscious wearer, the quality of being highly wearable, and effectiveness and reliability over time. For example, it is shown that: 1) there is very little evidence of a reliability problem with PFDs in the accident data, and 2) nearly three-fourths of the fatalities, for whom time in the water is known, occur in the first 15 minutes. Thus, it appears that a PFD can save many lives if it is worn, it may not need to function for a long time (especially with the advent of level flotation in the future), and hypothermia protection may not be of great importance in a great number of cases where fatalities occur in such a short time.

ARM is used to generate quantitative estimates of the benefits of hypothesized and actual changes in recreational boating (changes in PFD wear, changes in PFD properties, i.e., the Life Saving Index, educating boaters to stay with their boats, and the effects of hypothermia and level flotation). The approach of breaking down each problem into multiple factors or states has proven fruitful in terms of generating meaningful benefit estimates. This approach is necessitated by the strong interrelationships between factors which determine whether a boating accident victim lives or dies.

The current annual benefit for PFDs is estimated to be between 50 and 124 lives saved. The upper bound for the potential benefits of level flotation is estimated to be 255 lives saved. Since the ARM data base is historical, and very few level flotation boats are included in it, only an upper bound could be generated for that case. It was estimated that between 26 and 202 boating deaths per year are influenced by hypothermia.

Finally, a statistically significant linear relationship is found between the average Life Saving Index for the PFD population and the estimated benefits (lives saved) from PFDs. The linear relationship provides for the computation of the effects of changes in PFD parameters (wearability, accessibility, reliability, and effectiveness) on a victim's chances for survival. Basically, the relationship shows a benefit of approximately 3.8 lives saved for each .01 increase in the average LSI.

SECTION VII - ANALYSIS OF THE LIFE-SAVING INDEX (LSI) SYSTEM

Section VII is concerned with the application of the LSI to the PFD approval process. This section starts out with a review of the LSI and a description of its application to three prevalent accident scenarios.

Next, justification is given to:

- Not requiring a priori use of automatic actuators on inflatables. Instead, due to the reliability problems of present automatic actuators coupled with the relatively few cases where automatic actuation would result in additional lives saved, we recommend that the overall LSI be defined such that the capability to automatically provide buoyancy increases the overall LSI. Further work on automatic actuators is recommended.

- Not requiring a priori hypothermia protection or unconscious wearer righting capability (although to achieve the minimum LSI which we recommend, the manufacturer may choose to provide these capabilities).

In light of the above decisions, the wearability, reliability, and effectiveness values were combined into the LSI and are shown in Table VII-2 for typical devices currently in the marketplace as well as inflatables which could be built based on modifications to devices already in the marketplace.

The following points are important:

- The current Type II yoke device, which in 1975 comprised almost 50% of the available devices in use, has an overall LSI of only 0.11 as opposed to over 0.25 for some inflatables, and 0.24 for a Type III vest.

- The reliability indices of feasible inflatables actually exceeds that of many presently approved devices.

- Hybrids (one of which is Coast Guard approved) have the highest overall LSI of currently available devices.

- It should be possible to allow future approval of inflatables with life-saving capabilities twice that of Type II yokes and having individual wearability, reliability, and effectiveness indices also higher than the corresponding indices for Type II yokes.

Next, a discussion of two procedures for allowing the approval of devices based on the LSI is presented and summarized. The more feasible of the two alternatives consists of the implementation of a "Type X" device, in addition to the current Coast Guard standards for PFDs. The Type X device would use approval/certification procedures (three alternatives are given) based on the work done under this project. A manufacturer could elect to submit his device for Type X approval if it was not designed to the Type I, II, III, or IV criteria. This approach allows high life-saving effectiveness devices to enter the market if the public desires them, but does not force anyone to buy a higher potential, but more costly, device than the inexpensive AK-1. Assuming that the Type X devices enjoy a market reception on the order of the reception given to Type III (the costs for Type Xs and Type IIIs would be similar), an increase in adult lives saved of 48 per year is calculated. If the Type X certification program were extended to include children's devices, the benefit would be even higher. The second alternative, requiring a minimum LSI of 0.23 for all PFDs, which produces a predicted benefit of 105 lives per year is presented, but the cost per life saved appears to be excessive.

One advantage of the Life-Saving Index System is that it has the potential of providing significant consumer information on the value of his flotation device. While a number like 0.25 may be selected for the minimum LSI for Type X, the Coast Guard may choose to have classes within Type X of higher LSI devices. As an example:

Type	Minimum LSI
XC	0.25
XB	0.30
XA	0.35
XAA	0.40
XAAA	0.45

could be used whereby manufacturer's advertising and Coast Guard education could be used to inform people of the availability of higher LSI devices. This consumer information would help the manufacturer who chooses to build a high LSI, but possibly more expensive, Type X device as well as the more imaginative manufacturer who may be able to achieve a "breakthrough" with a high LSI, inexpensive device using new materials or actuator technologies. If the above was implemented and technological breakthroughs achieved, a significantly greater benefit than 48 lives per year could be realized.

Next, we present an anaylsis of three alternative approval/certification procedures for the Coast Guard to consider, and the costs for each are computed. The cost of Type X approval is in each case comparable to that for the present approval system.

Finally, a discussion of the possible impact of level flotation on PFD performance criteria is given. Due to lack of data on level flotation boats in the ARM data base (there are very few level flotation boats in the historical data base), the PFD level flotation interaction cannot be analyzed at present using ARM. A more complete analysis using 1978 accident data (which should contain some level flotation boats), is recommended. On balance, we believe that our benefit estimates for the Type X approval are conservative in view of the possible synergistic effects of level flotation coupled with more wearable PFDs.

In summary, this section builds a solid case for the "applicability" of this research within the Coast Guard's PFD approval process. With additional study, it is likely that a more effective means of implementing the LSI concept to save lives will be identified. Our effort to date has concentrated on developing a technology applicable to a more flexible PFD approval procedure. Future phases of the PFD project should be concerned more deeply with optimizing the use of that technology in the Coast Guard's operational PFD approval program.

SECTION II
THE LIFE-SAVING INDEX (LSI)

Coast Guard statistics (Reference 1) show that between 1400 and 1800 people die in recreational boating accidents each year. The same source also reports that approximately 90% of these deaths are due to drowning. In order to reduce the number of drownings, the Coast Guard has promulgated PFD standards and carriage requirements and undertaken research concerning the use and functioning of PFDs. The present report represents the second phase of this research undertaken by Wyle Laboratories. Previous work by other contractors indicated that it might be beneficial to develop a "life-saving index" (LSI). The LSI is a quantitative estimate of a PFD's life-saving capability.

The initial version of the LSI was defined as the product of the physical effectiveness, reliability and wearability of the PFD (Reference 2):

$$\boxed{LSI = I_E \times I_R \times I_W}$$

where

I_E = Physical effectiveness; the probability that the PFD maintains the wearer in a position which permits continuous breathing.

I_R = Reliability; the probability that the PFD performs as designed.

I_W = Wearability; the probability that the PFD is worn by the victim when he enters the water in a marine accident.

This section reviews the further development of the LSI undertaken by Wyle Laboratories to provide the Coast Guard with a more flexible and effective regulatory mechanism for evaluating PFDs.

The existing PFD approval process evaluates only certain aspects of PFD effectiveness and reliability. These parameters are reasonably high for most PFDs. However, the wearability and accessibility of currently approved PFDs is low. Studies conducted by Wyle show that only 7% of the boating population routinely wears a PFD (see Section III of this report). The low rate of PFD use seriously hinders the overall life-saving capability of PFDs. Section VI of this report estimates the benefit or loss in number of lives as a function of changes in the rate of PFD use.

No matter how effective or reliable a PFD is, it cannot save lives if it is not worn or accessible to boating accident victim. The purpose of the present project is to develop a method for evaluating the overall life-saving capability of PFDs. The proposed method is called the Life-Saving Index (LSI) System. The LSI System is composed of: a) test methods for evaluating PFD wearability, accessibility, effectiveness and reliability, b) indices of PFD wearability, accessibility, effectiveness, and reliability, and c) the LSI, which is a quantitative scale of the life-saving capability of PFDs. The LSI System is applicable to diverse types of PFDs, including inflatables and hybrids as well as inherently buoyant devices. The LSI System gains its wide applicability from the fact that it is performance-oriented. The LSI System predicts the actual life-saving performance of the PFD in the recreational boating environment. Some of the advantages of the LSI System relative to the current PFD approval process include:

- The LSI System will help foster the development of innovative PFD designs by industry and will provide the Coast Guard with a method for evaluating the life-saving capability of these designs.
- The LSI System permits the evaluation of trade-offs between reliability, wearability, accessibility, and effectiveness.
- The LSI System makes it possible to compare diverse PFDs on a common continuum of life-saving potential.

In developing the LSI System, a revision of the initial life-saving index was necessary. Data collected by Wyle showed on the one hand that PFD wear is very low, but on the other hand that PFDs can be effective when held or donned in the water. These considerations suggest that it may be cost-effective to consider PFD accessibility as well as wear. An important point to consider is that accessibility is probably easier to change than wearability; i.e., it will be easier to induce boaters to keep PFDs accessible than to wear them, since the former involves less discomfort.

Using accessibility as a supplement to PFD wear requires an expansion of the definition of PFD physical effectiveness. In studying the effectiveness of PFDs, previous researchers have assumed that they would be worn. The present report considers PFD effectiveness when held or donned in the water as well as when worn.

The consideration of accessibility also allows for the evaluation of throwable PFDs. The revised LSI provides a way of comparing the life-saving capability of wearable and throwable PFDs.

The following equation represents the life-saving capability of an individual PFD. It is presumed that the physical effectiveness of a PFD depends upon whether it is worn or held, hence two types of effectiveness appear in the equation. The equation also provides for the possibility that an accessible PFD may be donned after the victim of an accident enters the water.

$$LSI = [I_W \cdot E_W + I_{AC} \cdot P_D \cdot E_W + I_{AC} \cdot P_H \cdot E_H] \cdot R$$

where

I_W = The probability that the PFD is worn immediately prior to entering the water in an accident (the wearability index).

I_{AC}* = The probability that the PFD is accessible to a boater but not worn initially upon entering the water in an accident (accessibility index).

P_D = The probability that the accident victim dons the PFD in the water.

P_H = The probability that the accident victim holds or lies upon the PFD in the water.

E_W = The probability that the PFD maintains or turns the wearer in the water to a position with a minimum required freeboard to the lower respiratory passage within a specified time limit (effectiveness when worn).

E_H = The probability that the PFD provides a minimum required freeboard to the lower respiratory passage for a relaxed person holding or lying upon the device in the water (effectiveness when held).

R = The probability that a PFD will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended (reliability).

---

*As presented in Section III, our accessibility indices must be based on the pre-accident location of the PFDs. Some modification of the accessibility indices to reflect post, as opposed to pre, accident conditions may be required and is discussed in Section VII.

Figure II-1 shows the LSI concept subjectively, and Figure II-2 shows how the LSI equation was derived using probability theory. The three major branches of the fault tree correspond to three modes of PFD use. Each mode contributes to the overall life-saving capability of the PFD. The left-most branch covers the possibility that the PFD is worn when the victim enters the water. The middle branch allows for the possibility that the PFD is donned after the victim has entered the water. The third branch covers the possibility that the victim holds or rests upon the PFD rather than donning it in the water.

Note that P_D and P_H are conditional probabilities; i.e., the probability that the PFD is donned (or held) given that it is accessible and functions reliably. Effectiveness when worn (E_W) is conditional on the event that the PFD is worn (either before entering the water or because it was accessible, functioned reliably, and was donned). Effectiveness when held is conditional on the event that the PFD was accessible, functioned reliably, and was held. It is assumed that the reliability (R) of the PFD is independent of its wearability (I_W) and accessibility (I_{AC}).

The LSI model was further expanded to take into account the fact that accident victims enter the water in varying conditions. Table II-1 lists three types of victim conditions and shows how the definitions of the LSI parameters change as a function of victim's condition. In Case A the victim is unconscious or incapacitated (e.g., seriously injured) upon entering the water or immediately thereafter. In this case the victim obviously cannot hold onto a PFD or don it in the water; hence the effectiveness of the PFD when held (E_H) is zero and the probability of donning the PFD in the water (P_D) is zero. The effectiveness of the PFD when worn (E_W) is measured using the most severe test procedure (see Section IV). The head-forward, stationary test is recommended because the victim could (in the worst case(end up with no headway and with his face forward in the water. This definition of effectiveness for Case A is conservative. For rough water conditions, the head forward, stationary test might be too stringent. Case A also requires that the PFD's buoyancy mechanism work passively (i.e., without manipulation by the victim). This means that the system must have inherent buoyancy or an inflatable component which automatically actuates when submerged in water.

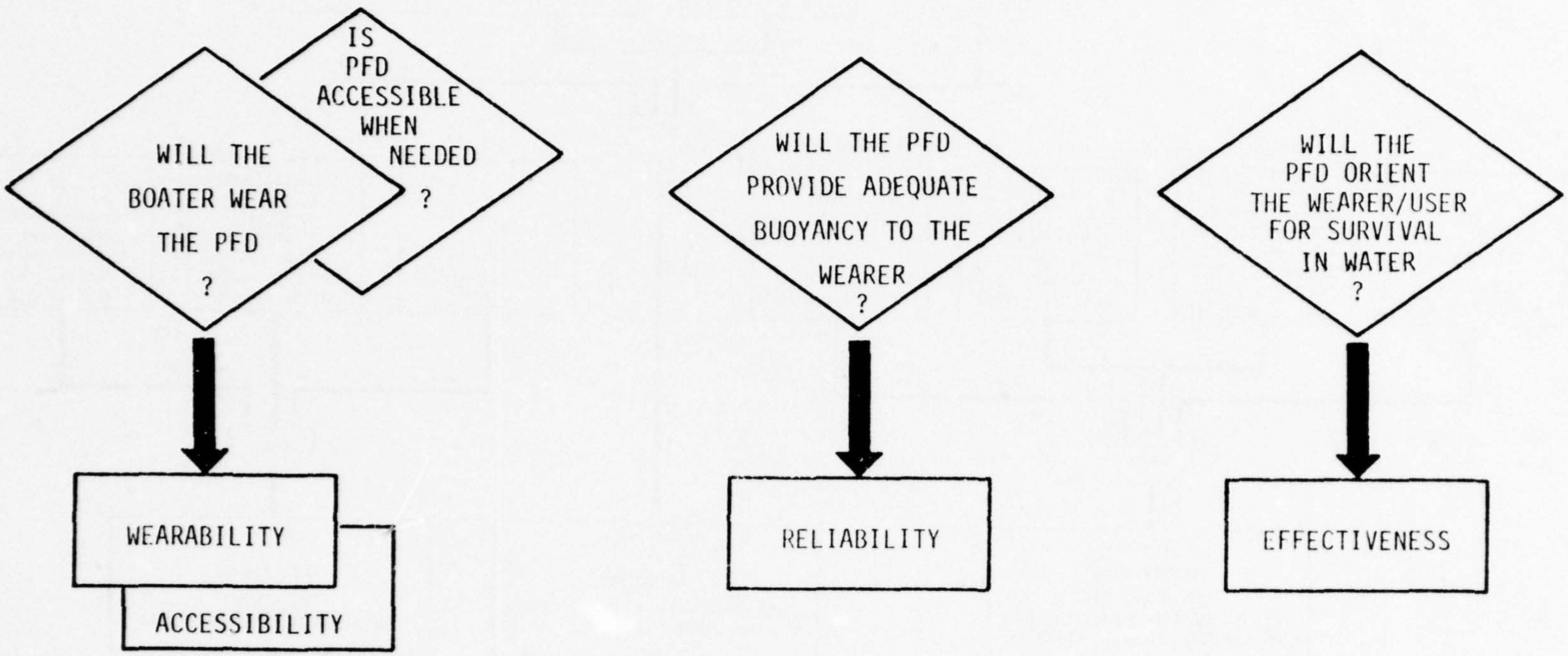
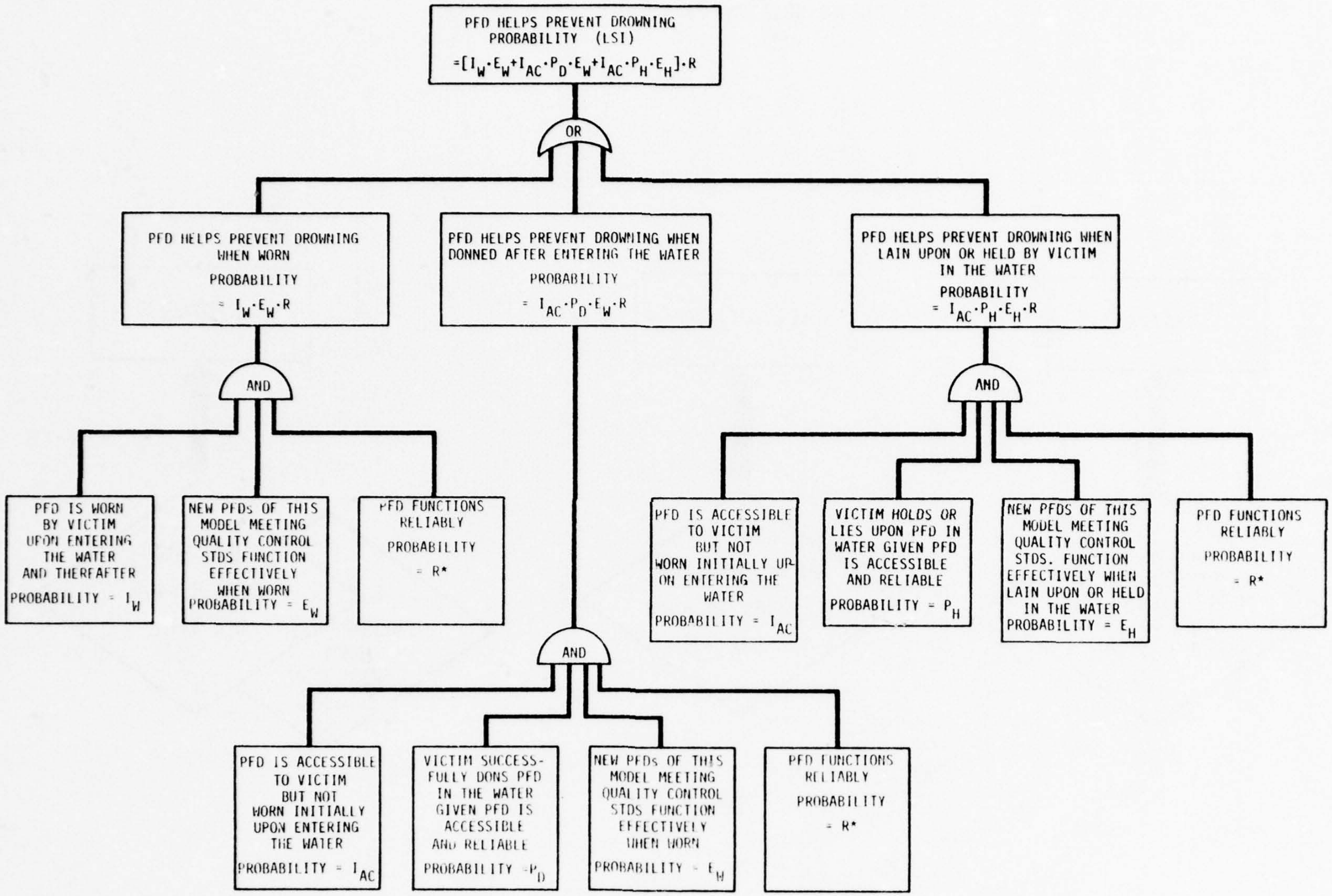


FIGURE II-1. BASIC PARAMETERS IN THE LSI



*RELIABILITY ENCOMPASSES BOTH QUALITY PROBLEMS AND CHANGES IN PFD PERFORMANCE WITH AGE.

FIGURE II-2. BASIC LSI FAULT TREE

TABLE II-1. DEFINITIONS OF PARAMETERS OF THE LIFE-SAVING INDEX (LSI)

CASE A: VICTIM UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER	CASE B: VICTIM CONSCIOUS UPON ENTERING THE WATER BUT BECOMES UNCONSCIOUS WHILE IN THE WATER	CASE C: VICTIM CONSCIOUS AND REMAINS SO WHILE IN THE WATER
ESTIMATED PERCENTAGE OF ADULT RECREATIONAL BOATING ACCIDENT VICTIMS ANNUALLY		
0.4 - 14.0	1.1 - 7.7	78.3 - 98.5
RECOMMENDED USAGE ENVIRONMENTS		
Significant likelihood of sudden impact, e.g., motor boat racing, high speed water skiing, white-water boating.	Cold water environments with long expected time-to-rescue.	Warm water and/or short time-to-rescue environments.
EFFECTIVENESS		
E_{W_A} = The probability that the PFD turns the unconscious/relaxed wearer to a position with adequate freeboard (head forward, stationary test).	E_{W_B} = The probability that the PFD turns the unconscious/relaxed wearer to a position with adequate freeboard (head forward, moving test).	E_{W_C} = The probability that the PFD maintains the conscious-relaxed wearer in a position with adequate freeboard (head back, stationary test)
$E_H \equiv 0$	$E_H \equiv 0$	E_H = The probability that the PFD maintains a conscious/relaxed user in a position with adequate freeboard when the user holds or lies upon the PFD in the recommended manner.
$P_D = 0$	P_D = The probability that the victim successfully dons the PFD in the water.	P_D = The probability that the victim successfully dons the PFD in the water.
WEARABILITY		
I_W = The probability that the PFD is worn by the victim of a boating accident upon entering the water and continues to be worn while in the water. I_{AC} = The probability that the PFD is accessible to the victim of a boating accident but not worn initially upon entering the water.		
RELIABILITY *		
R_A = Probability that the minimum effective buoyancy is achieved and maintained through the use of inherently buoyant material, automatic actuation of an inflatable, or both	R = Probability that the minimum effective buoyancy is achieved and maintained through the use of inherently buoyant material, automatic actuation, manual actuation or any combination.	R = Probability that the minimum effective buoyancy is achieved and maintained through the use of inherently buoyant material, automatic actuation, manual actuation, or any combination.

*It is recommended that oral inflation and topping-up capability be required on all inflatables and hybrids in all cases as a back-up system.

In Case B, automatic actuation is not required for inflatables since the victim is conscious and not incapacitated when he enters the water. Manual actuation (meaning the wearer must act to initiate inflation by CO_2 or other system) is recommended. In Case B effectiveness when worn is measured by using the head-forward, moving test. This test is less stringent than the head-forward, stationary test, but still conservative considering the victim's condition. Since the victim is conscious and capable when he enters the water, one might presume that he adopts a head-back position and simply remains in that position even after he becomes unconscious. If one were comfortable with this presumption, the PFD would be required only to maintain the wearer in a head-back position. However, the victim might attempt to swim and become exhausted in a head-forward position, or be buffeted into a head-forward position by rough water conditions. The head-forward, moving test is therefore recommended.

Figure II-3 shows the logic tree which defines the overall LSI for a PFD, taking into account the three types of victim conditions. The logic tree identifies three cases, depending on the victim's condition, which require different types of PFD performance characteristics.

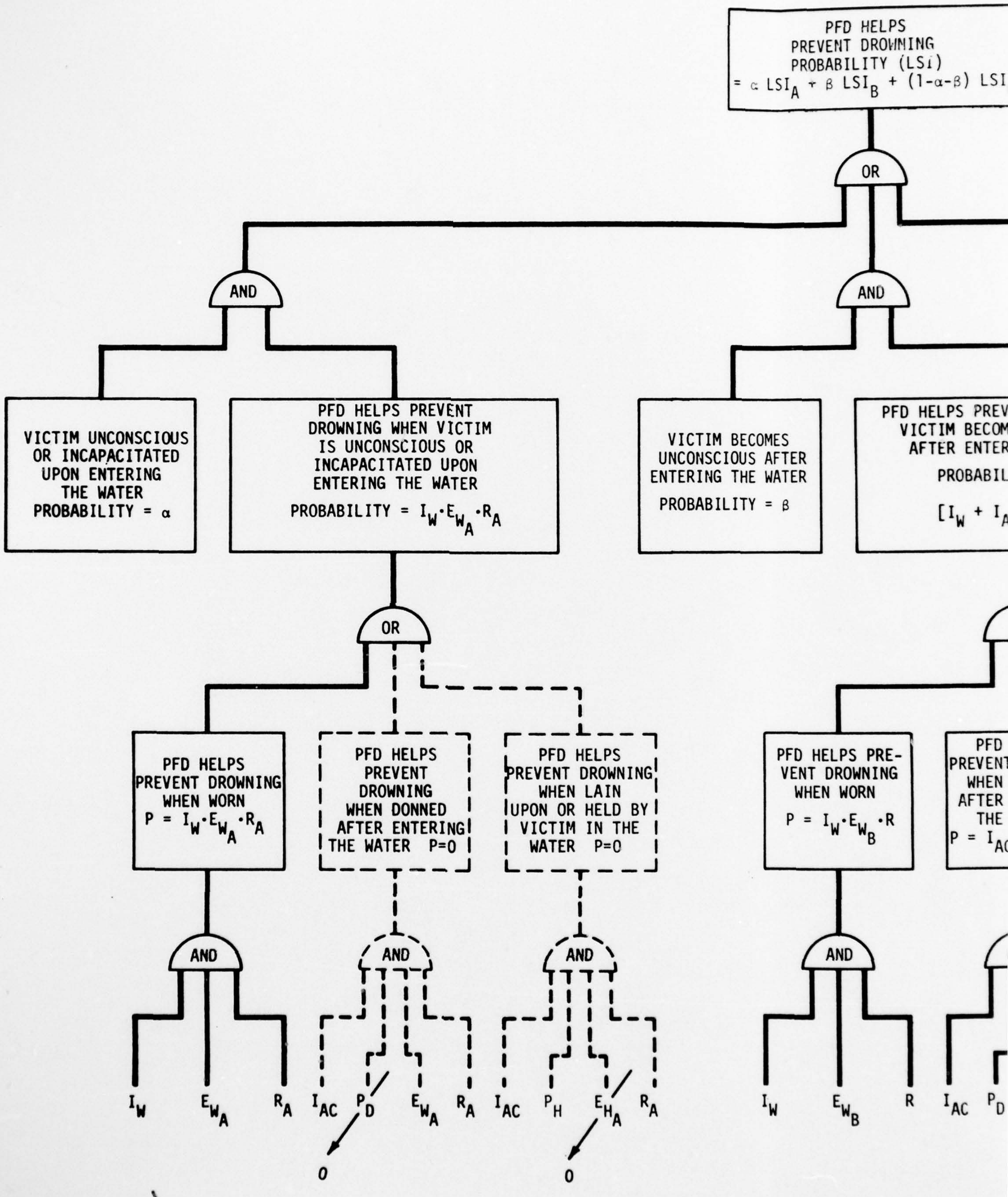
The overall LSI can be expressed as a *weighted combination* of individual LSIs for three cases:

$$LSI=\alpha\cdot LSI_A+\beta\cdot LSI_B+(1-\alpha-\beta)\cdot LSI_C$$

where

α = the proportion of recreational boating accident victims who enter the water unconscious or incapacitated.

β = the proportion of recreational boating accident victims who become unconscious after entering the water. Once test methods are developed for evaluating the thermal protective capacity of PFDs, this number would be modified to reflect the thermal protective performance of the candidate PFD. The higher the thermal protective capacity of the candidate PFD, the lower β would be for that PFD.



PFD HELPS PREVENT DROWNING PROBABILITY (LSI) = α LSI_A + β LSI_B + (1-α-β) LSI
OR
AND
AND
VICTIM UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER PROBABILITY = α
PFD HELPS PREVENT DROWNING WHEN VICTIM IS UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER
PROBABILITY = I_W·E_WA·R_A
VICTIM BECOMES UNCONSCIOUS AFTER ENTERING THE WATER
PROBABILITY = β
PFD HELPS PREV
VICTIM BECOM
AFTER ENTER
PROBABIL
[I_W + I_A
OR
PFD HELPS PREVENT DROWNING WHEN WORN P = I_W·E_WA·R_A
PFD HELPS PREVENT DROWNING WHEN DONNED AFTER ENTERING THE WATER P=0
PFD HELPS PREVENT DROWNING WHEN LAIN UPON OR HELD BY VICTIM IN THE WATER P=0
PFD HELPS PRE-VENT DROWNING WHEN WORN
P = I_W·E_WB·R
PFD
PREVENT
WHEN
AFTER
THE
P = I_AC
AND
AND
AND
AND
I_W
E_WA
R_A
I_AC
P_D
E_WA
R_A
I_AC
P_H
E_HA
R_A
0
0
I_W
E_WB
R
I_AC
P_D

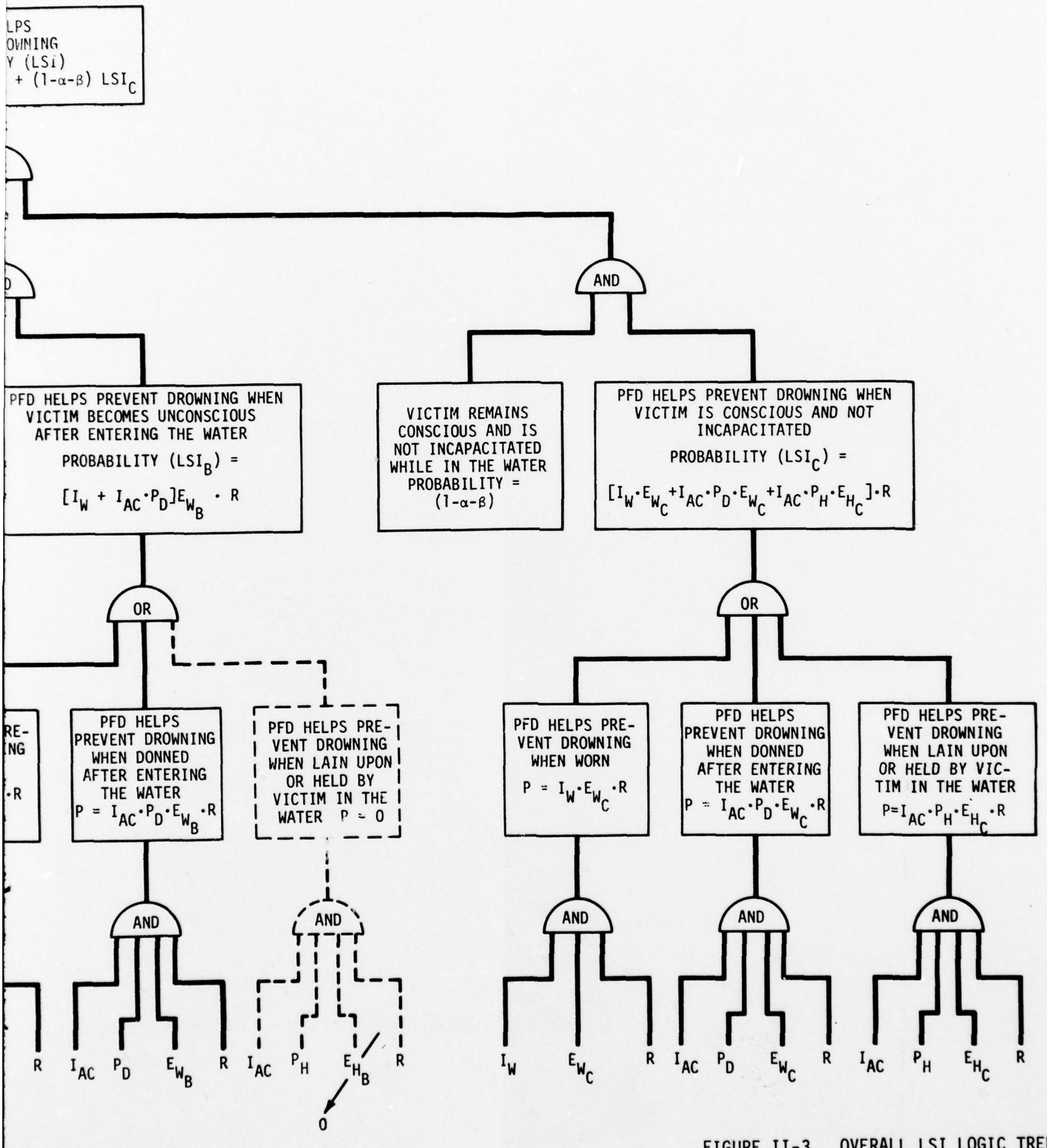


FIGURE II-3. OVERALL LSI LOGIC TREE

2

$$LSI_A = I_W \cdot E_{W_A} \cdot R_A$$

$$LSI_B = [I_W + I_{AC} \cdot P_D] \cdot E_{W_B} \cdot R$$

$$LSI_C = [I_W \cdot E_{W_C} + I_{AC} \cdot P_D \cdot E_{W_C} + I_{AC} \cdot P_H \cdot E_H] \cdot R$$

In the above formula, R_A is the reliability with which the PFD automatically provides the required buoyancy. R_A is by definition zero for manually actuated inflatables with no inherent buoyancy.

In the above formula, LSI_A, LSI_B, and LSI_C are conditional probabilities. LSI_A is the probability that the PFD helps prevent drowning given that the victim is unconscious or incapacitated upon entering the water. LSI_B is the probability that the PFD helps prevent drowning given that the victim becomes unconscious while in the water. LSI_C is the probability that the PFD helps prevent drowning given that the victim remains conscious while in the water.

In the proposed LSI System, the LSI serves as the primary tool for evaluating PFDs which are candidates for certification or approval (see Figure II-4). The performance parameters of the PFD (wearability, accessibility, effectiveness, and reliability) would be measured as detailed in Sections III through V of this report. The LSI can then be computed and compared to a minimum LSI established by the Coast Guard. Only those candidate PFDs which meet or exceed the minimum LSI would be certified or approved. In addition to establishing a minimum LSI, the Coast Guard may deem it desirable to establish minimums for the indices of effectiveness and reliability.

REFERENCES

1. United States Coast Guard, Boating Statistics 1974, CG-357.

2. Greenhouse, L., Kerne, B. and Weiers, D., A Reliability Investigation of Personal Flotation Devices, Phase I, Operations Research, Inc., CG-D-13-74, 1973. NTIS No. AD-770-210.

THE LIFE-SAVING INDEX SYSTEM

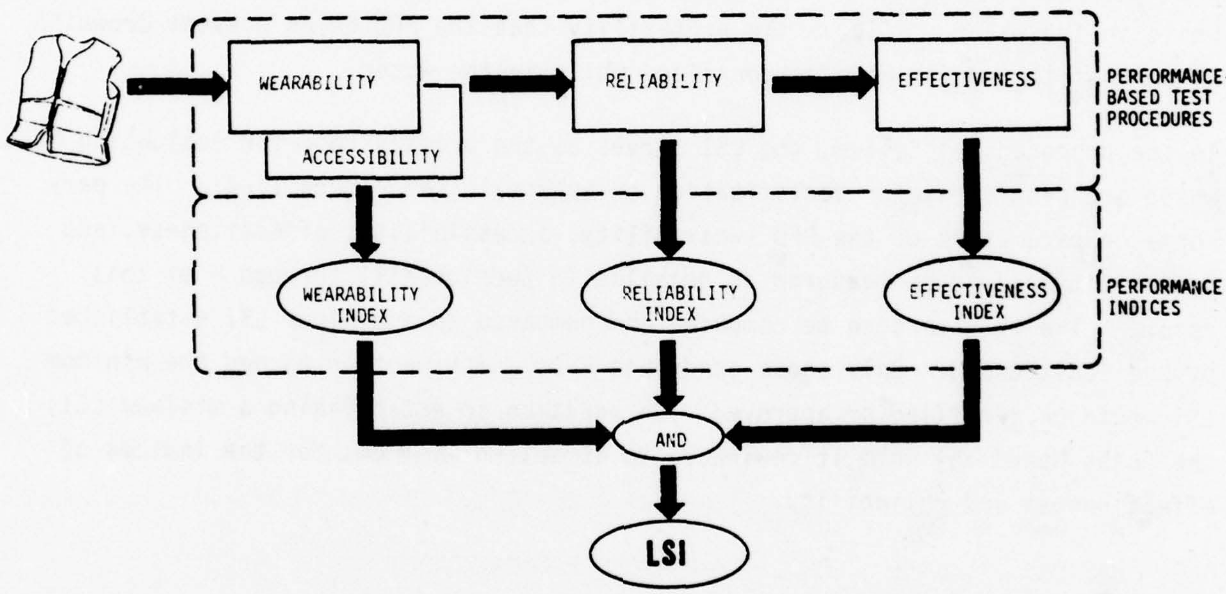


FIGURE II-4. OVERVIEW OF THE LIFE-SAVING INDEX SYSTEM FOR EVALUATING PFDS

SECTION III

DEVELOPMENT OF A TEST METHOD AND MODEL FOR PFD WEARABILITY AND ACCESSIBILITY

TABLE OF CONTENTS

SECTION III LIST OF FIGURES

SECTION III LIST OF TABLES

SECTION III
DEVELOPMENT OF A TEST METHOD AND MODEL FOR PFD WEARABILITY AND ACCESSIBILITY

1.0 SUMMARY

The primary objectives of wearability/accessibility research were to: a) determine what factors influence the wearability and accessibility of PFDs, and b) to develop test methods and models for evaluating PFD wearability and accessibility.

Section 3.0 describes an observational study of PFD accessibility and wear. The goal of this study was to obtain accurate estimates of PFD wear and accessibility in recreational boating throughout the United States. The study was designed in such a way that it eliminates or minimizes several serious methodological flaws in previous research. The results show that the overall percentage of recreational boaters wearing PFDs is 7.1%. The study also shows that PFD wear and accessibility depend upon the boater's activity, boat size, the wearer's sex and age, as well as the properties of the PFD.

A second set of studies (see Section 4.0) was undertaken to develop methods for predicting the wearability and accessibility of PFDs in recreational boating. Sixty-seven different models of PFDs encompassing most of the major varieties available world-wide were distributed to recreational boaters for their use and evaluation. Thirty-six participants in that study produced a data base of 185 PFD evaluations. Each evaluation encompassed PFD properties (including appearance, comfort, compatibility with the boater's activities, image, perceived effectiveness and reliability, wearability, and accessibility); boater demographics, activities, and attitudes; and situational variables (boat type, boat length, weather conditions, etc.). Multivariate statistical techniques, including factor analysis, canonical correlation analysis, and multiple linear regression were used to develop indices of PFD wearability and accessibility. It is demonstrated that these indices are valid and reliable predictors of PFD wear and accessibility. The wearability index matches closely the wear rates obtained by observing boaters in the field. An accuracy of prediction of $\pm$ 5% for both wearability and accessibility can be achieved using a panel of about 12 boaters to evaluate PFDs.

The final section of this chapter describes test procedures for the evaluation of PFD wearability and accessibility based on the results of the above study. This section also offers some recommendations for further research and development.

2.0 INTRODUCTION

2.1 Background

The life-saving capability of PFDs depends critically upon wearability. The wearability of a PFD is defined as the probability that the PFD is worn by the victim when he enters the water in a boating accident. At the inception of this project, PFD effectiveness and reliability were believed to be reasonably high for Coast Guard approved devices. However, reports from a variety of sources suggested that the wearability of PFDs is low.

The role of PFDs in boating accidents involving fatalities was reported in Coast Guard statistics (Reference 1). Of fatal accidents in which PFDs are known to have been available, they were reportedly not used or used improperly in 71% of the cases. In a separate review of boating accident reports, it was estimated that over 90% of the drowning victims could be saved by the use of PFDs (Reference 2).

These findings from accident reports have been corroborated by surveys of boaters in non-accident situations. In a nationwide mail survey of boat operators from October 1973 through January 1974 (Reference 3), the reported rates of PFD wear were 31% during good weather and 52% during foul weather.

Another study (Reference 4) reported somewhat lower rates of wear and found large differences between two samples. Atlanta and Miami boaters were asked to estimate the percentage of time they would wear various types of PFDs. For Atlanta respondents, the wear rate averaged over all types of wearable PFDs was 28.5%. For the Miami sample, the same figure was only 6.81%.

Both of the above studies (References 3 and 4) have certain methodological problems which probably inflate the estimate wear rates. One of these is that the data are self-reports; i.e., what the respondent says rather than what he actually does. The wear rates reported above may therefore be overestimated.

Another problem in both of the above studies is lack of the representativeness of the sample of respondents. The Reference 3 report surveyed only boat owners. This sample is probably older, wealthier, and contains a larger proportion of males than the population of U.S. boaters. In addition, only 49.8% of the initial sample returned questionnaires. Those people who take the time and trouble to respond may be more cautious or conscientious people in general. In the Reference 3 study, the Atlanta respondents were people who attended a boat show. In Miami, the respondents were boaters at a particular marina. It is possible that the large difference in wear rates between Atlanta and Miami is in part due to the particular sites sampled.

In addition to attempts to document the rate of wear of PFDs, previous research has measured various design features of PFDs and boater's attitudes.

The Reference 4 study attempted to find design features and attitudes which were predictive of PFD wear. A questionnaire was administered to boaters at the Miami and Atlanta Test sites and the results were factor-analyzed. Two factors were identified - one "person" based and another "situation" based. The person based factor reflects consistency in respondent's answers to questions such as "I do wear or would prefer to wear a PFD at all times while boating" and "I would not be comfortable wearing a PFD." The situation based factor indicates that people who report wearing PFDs in, say, rough water also tend to report wearing PFDs under bad weather conditions. Only the person based factor was reasonably predictive of reported wear rate. While this result is interesting, it does not help to illuminate the reasons why people wear (or don't wear) PFDs.

In the same study, respondents were asked to rank PFD design parameters in importance for buying and wearing a PFD. Parameters such as effectiveness, reliability, freedom of movement and visibility were ranked highest for both buying and wearing. This result suggests that PFD wear would be high if people thought they were effective, reliable, etc. But the wear rate is very low. Either people don't believe that Coast Guard approved PFDs are effective, reliable, and so on, or this ranking of design parameters simply is not predictive of PFD wear. This result again illustrated one difficulty of survey research - people don't necessarily report what they actually do. Another problem in this study is that respondents

were not given the opportunity to try the PFDs on. The study documents reported preferences for PFD hue, intensity, pattern, material, etc. Unfortunately, no evidence is presented that these preferences are related to PFD wearing behavior.

A threshold wearability model is also reported in Reference 4. The model has certain shortcomings which are enumerated below (see Reference 5 for further details):

A. The model defines non-accident utility (P_{na}) as "Probability that a PFD of a given type appeals to a given individual's esthetic sense, predictions of comfort, feeling of freedom of movement, etc." One mathematical consequence of the model is that for any PFD for which $P_r(\text{worn}) \neq 0$ among recreational boaters, non-accident utility is the same for all PFDs and all boaters. It can be shown mathematically that the only possible value of P_{na}, under these conditions is 1.0.

B. One of the assumptions made is inconsistent with the whole idea of developing a wearability index. The following assumption appears on Page B-13: "An inherent assumption is that the fraction of time he would wear the PFD of his choice is the same as the fraction of time he would wear any PFD." This assumption means that PFD's properties have absolutely no influence on the probability that they well be worn. If one accepts this assumption, then it is futile to worry about PFD wearability.

Another research report (Reference 2) concludes that "no Coast Guard approved PFD exists that would be acceptable to the recreational boater for wearing at all times while afloat." Based on this conclusion, it is recommended that advanced concepts design efforts be directed toward PFDs worn around the waist. The report also recommends inflatable PFDs to reduce weight and bulk.

2.2 Approach

The original purpose of this part of the PFD research project can be described as follows:

1) To determine what factors influence the wearability of PFDs and to what extent.
2) To develop an index or other means of evaluating wearability for use as a regulatory tool.

Since its inception, the scope of this part of the project has been broadened to encompass PFD accessibility as well as wear. There is an increasing awareness among those who have studied PFD use that it is probably impossible to get all boaters to wear PFDs all of the time. The recognition of this problem is implicit in the Coast Guard's approval of buoyant cushions as PFDs and in the wording of the PFD regulations, which stress that PFDs should be kept readily accessible.

Accessibility of a particular model PFD is defined as the probability that the PFD will be accessible to the boater immediately after he/she enters the water in a recreational boating accident, given that the PFD was on board.

The term wearability has historically been used in two different ways. When one asks "How wearable is this PFD?", he/she is usually referring to the design features of the PFD. In other words, wearability is more or less synonymous with comfort when used in this sense. In written contexts, however, wearability is usually defined as "the probability that a boater will be wearing a particular type of PFD when he/she enters the water in a recreational boating accident," given that a PFD of that type was on board. Wearability as defined in this second way depends not only on the design features of the PFD, but also upon the person's attitude and motivation and the environment. In fact in some environments, PFD design may have little or nothing to do with wearability as long as the PFD is perceived as effective and reliable.

A two-fold approach to the wearability/accessibility problem has been pursued in the present project. Section 3.0 describes an observational study of PFD accessibility and wear. The goal of this study was to obtain accurate estimates of PFD

wear and accessibility in recreational boating throughout the United States. The study was designed in such a way that it eliminates or minimizes several serious methodological flaws in previous research. The observational study identifies significant conditions in the boating environment which affect PFD use and provides valuable base line data and parameters for the development of PFD evaluation procedures.

A second set of studies was undertaken to develop a method for predicting the wearability and accessibility of PFDs in recreational boating. These studies were directed at developing: 1) test procedures for evaluating the wearability and accessibility of candidate PFDs, and 2) indices of wearability and accessibility based on these test procedures which serve as inputs to the Life-Saving Index (LSI). Two pilot studies in this series were presented in the Phase I PFD research final report (Reference 5). The recommendations of the pilot work were incorporated into a full scale study of wearability and accessibility in Phase II. This study examines the effect of PFD properties, boater characteristics and attitudes, and situational/environmental factors on PFD wearability and accessibility. Factor analysis, canonical correlation analysis, and multiple regression analysis are used to develop indices of wearability and accessibility. It is demonstrated that these indices are valid and reliable. The predicted wearabilities of PFDs currently in the field match closely the results obtained in the observational study. An accuracy of prediction of $\pm 5\%$ for both the wearability and accessibility indices can be achieved using as few as 12 boaters to evaluate PFDs.

The final section describes test procedures for the evaluation of PFD wearability and accessibility based on the results of the above study. This section also offers some recommendations for further research and development.

3.0 OBSERVATIONAL STUDY OF PFD ACCESSIBILITY AND WEAR

The large-scale study assessed PFD wear and accessibility by direct observation at seven locations across the Continental United States. The percentage of people wearing PFDs, the number of accessible PFDs aboard, the percentage of accessible PFDs worn, and the distribution of various types of accessible PFDs were tabulated. Differences in these measures as a function of location, boating activity, age and sex of the boater, boat length and type, and type of PFD are reported. For example, the wearability of a PFD (percentage of accessible PFDs worn) depended on geographic location, air temperature and activity. The most wearable device for fishing was not the most wearable for waterskiing or other activities. The results are used to generate recommendations for educational and regulatory programs aimed at improving the life-saving capability of PFDs.

The present study departs from previous work in two important respects. First, direct data on PFD use was obtained by observing PFD use in the field. This method eliminated the problem of bias in self-reports and also improved the representativeness of the sample. The sample of people observed was not limited to operators or boat show attendees, but included all the people on board sampled boats. To further improve the representativeness of the sample, observations were taken at sixteen widely scattered sites across the Continental U.S. The sample included both inland and coastal locations. The second important feature of the present study is its attention to PFD accessibility as well as wear.

3.1 Method

A list of sites at which observations were collected is shown in Table III-1 . In total, 995 boats and 2448 people engaged in recreational boating activities were observed and/or photographed. In addition, 33 interviews were conducted, 22 at the New York site, six at Gem Beach, Ohio, and five in San Diego. The data were collected during July and August 1975, except for the Ft. Lauderdale and Tampa sites where the data were taken in October and March 1975, respectively.

At most locations, observers worked in pairs and recorded the same boat simultaneously. One observer photographed the boat and, as time allowed, looked for the pertinent information. The other observer either spoke into a tape recorder or wrote on a standardized data form. No effort was made to select one type of boat over another for observation.

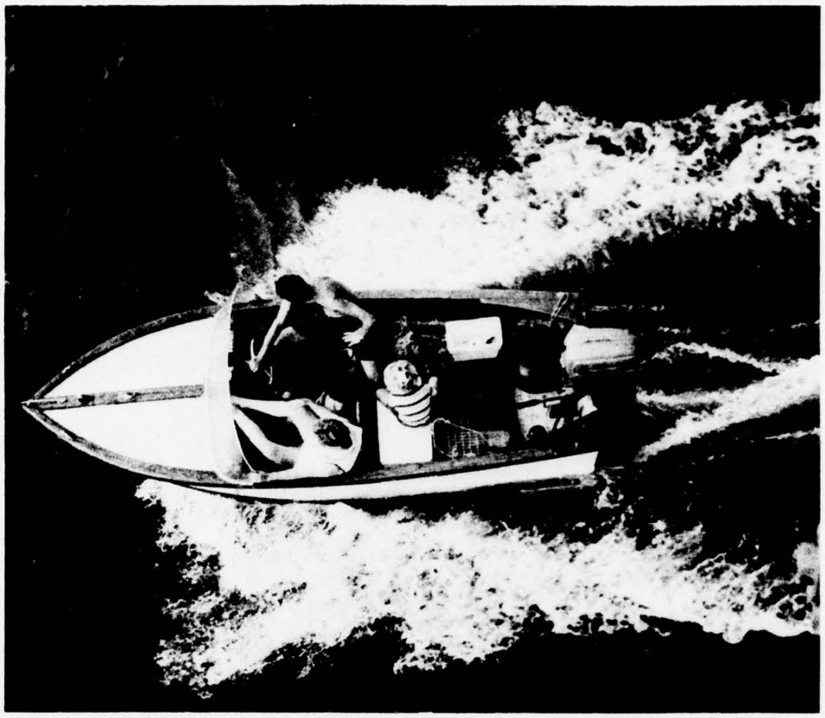
TABLE III-1. SAMPLED LOCATIONS

Location	General Areas Sampled	No. of Boats
NE Coastal	Wareham, Massachusetts	10
	Townsend Inlet, New Jersey	17
	Bayshore, L.I., New York	170
NW Coastal	San Francisco, California	23
	Oakland, California	10
	Benicia, California	1
	Deception Pass, Washington	14
	Seattle, Washington	1
SW Coastal	San Diego, California	163
SE Coastal	Ft. Lauderdale, Florida	23
	Tampa, Florida	332
SW Inland	Lake Havasu, Arizona	77
	Lake Meade, Nevada	5
SE Inland	Guntersville Lake, Alabama	54
Great Lakes	Port Clinton, Ohio	20
	Gem Beach, Ohio	75

Photographs and observations were typically made from a low bridge or other elevated position, usually 15-40 feet above the water. Photographs were taken from directly above open boats and slightly from the stern of enclosed boats, so as to maximize visibility of the occupants and PFDs. Color slides were taken with a 35 mm camera equipped with a telescopic lens when necessary. Two examples of the observations are shown in Figure III-1 .

The interviews used a standardized form which asked about PFD preferences, attitudes related to PFD use and functioning, and the number of PFDs on board which were not in view or accessible. An effort was made to select a varied sample of persons, boat types and sizes. The questions were directed to operators and took place at marinas and launch ramps.

Boats were classified according to type, overall length (<16 ft, $\geq$16 ft but <20 ft, and $\geq$20 ft), the apparent activity of the occupants, the age and sex of the people on board, age and sex of people wearing PFDs, type of PFDs worn, and the number and type of PFDs accessible. Note was made of non-approved as well as approved flotation aids, including ski belts, inner tubes, air mattresses, and rubber rafts.



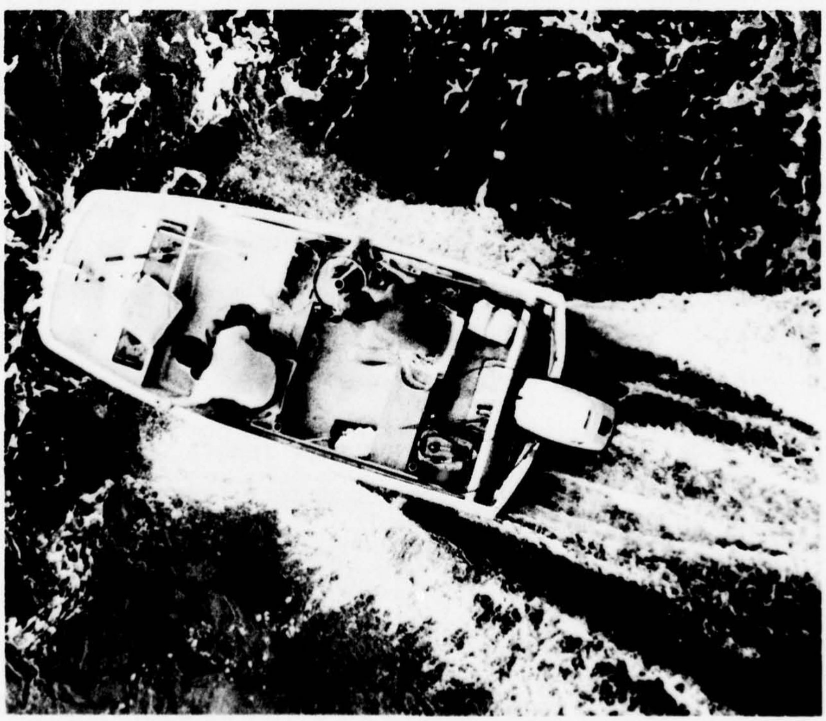


FIGURE III-1. EXAMPLES OF OBSERVATIONS IN THE OBSERVATIONAL STUDY OF PFD ACCESSIBILITY AND WEAR

Boats were classified under an activity even if they were not, at the moment, actively engaged in it. Since observations were generally taken from a low bridge, one would not expect to see certain activities in progress, such as water skiing. The chief evidence of activity was the equipment on board. In cases where no evidence of other activity was observed and the boat was clearly a recreational craft, the classification "pleasure cruising" was used.

Each observation was graded according to its quality. Observations for which the evaluator could be relatively confident that he saw or could have seen any accessible PFDs received a "√" mark. Observations where the rater could see the people on board well enough to determine whether they were wearing PFDs, but might have missed accessible PFDs were given an "X" mark. Other observations were discarded.

Of 995 usuable observations of boats, 490 were given "√" marks. Tabulations involving PFD accessibility are based upon "√" rated observations only. Each observation was coded onto data reduction forms by a pair of trained observers working together, and was later checked by a third observer. Special attention was given to assuring that a given boat was not counted more than once and to verifying the "√" classifications.

3.2 Results and Discussion

Characteristics of the Boats and People Observed

Characteristics of the observed boats are presented in Table III-2. The most frequent type of boat was the standard runabout, constituting 33% of the overall sample. The standard runabout included all boats with a closed foredeck, but no permanent superstructure above gunwale other than a windshield, canvas top and frame, or moveable hard top. The next most frequent type was cabin cruisers (22%). In order to be classified as a cabin cruiser, the boat had to have a permanent superstructure other than a windshield, canvas top and frame or moveable hard top and be primarily a recreational rather than fishing or work vessel. The third ranking type of boat was bowriders (18%). It will be noticed that small, lightweight boats, including open runabouts, rowboats, and johnboats, accounted for only 6% of the sample. Tabulation of the number of boats of various lengths produced a related result. Notice that boats less than 16 feet

TABLE III-2. PERCENTAGE OF BOATS OBSERVED BY TYPE, ACTIVITY AND OVERALL LENGTH

BOAT TYPE											
House and Pontoon	Cabin Cruiser	Standard Runabout	Bowrider	Center Console Fishing	High Performance	Bass	Open Runabout	Rowboat	Johnboat	Sail	Other
1	27	33	18	5	4	1	4	1	1	3	3

ACTIVITY[b]					OVERALL LENGTH (feet)		
Fishing	Pleasure Cruising	Water Skiing	Sailing	Other[a]	< 16	16 - 20	> 20
19.5	70.4	5.3	2.3	2.6	20.5	41.5	38.0

[a] Other activities include swimming, racing, skin diving, hunting and working.
[b] The sample of 332 boats at Tampa, Florida, were photographed from such a distance and angle that it was difficult to determine activity. These cases, therefore, do not appear in this tabulation.

TABLE III-3. PFD WEAR AS A FUNCTION OF AGE, SEX, AND TYPE OF PFD

Age and Sex	Percentage of Each Age and Sex Wearing Particular Types, Given That a PFD Was Worn: Type II Yoke[b]	Type III Vest	Type III Jacket	Ski Belt	Percentage of Each Age and Sex Wearing Any PFD
Adult Male	10.5	70.2	14.0	5.3	1.5
Adult Female	50.0	39.5	5.3	5.3	3.2
Teenage Male[a]	63.6	36.4	0	0	6.0
Teenage Female[a]	77.3	22.7	0	0	11.7
Child, Male	70.0	26.7	0	3.3	38.3
Child, Female	85.2	14.8	0	0	34.5
All Persons	57.4	35.7	4.0	2.8	7.1

[a] 12-18 years of age
[b] Predominately AK-1s.

TABLE III-4. PERCENTAGE OF PEOPLE OBSERVED WEARING PFDS BY LOCATION, BOAT LENGTH, TYPE AND ACTIVITY

LOCATION[a]							OVERALL BOAT LENGTH (ft)		
Southeast Inland	Northwest Coastal	Great Lakes	Southwest Inland	Southwest Coastal	Northeast Coastal	Southeast Coastal	< 16	16 - 20	> 20
22.5	9.9	8.3	7.3	5.0	4.8	3.3	9.8	9.1	4.4

BOAT TYPE				ACTIVITY			
House Pontoon Cabin Cruiser	Standard Runabout Bowrider High Performance Center Console Bass	Rowboat Johnboat Open Runabout Other < 16 Ft	Sail	Fishing	Pleasure Cruising	Skiing	Other
3.0	9.4	7.8	22.4	5.0	7.4	13.9	13.0

[a] Percentages not lying above a common line are significantly different (p < .05 or better).

overall length constitute only 20.5% of the sample. These figures are somewhat surprising in view of data which shows that the average length of boats sold in the United States was 14.2 feet in 1974 (Reference 6). This discrepancy may be at least partially due to differential rates of exposure for large and small craft. Another possible explanation concerns the manner in which the observation sites were chosen. Most of the sites were in major boating areas which had fairly dense boating activity. Since johnboats and other small, lightweight craft are often used for fishing and hunting, the operators may tend to avoid such areas. Indeed, it might be difficult to observe any large number of johnboats since their use tends to make them widely scattered rather than concentrated.

The distribution of boats by type differed considerably between locations. Of the boats in the northeast coastal sample, a high percentage were cabin cruisers (39%) and center-console fishing boats (10%). The northwest coastal sample was high on cabin cruisers (41%) and sailboats (22%). The locations involving small inland lakes - Lake Havasu and Guntersville Lake - were low on cabin cruisers (2% in each case). Lake Havasu, in line with its reputation, had a high percentage of high-performance boats (13%). Bass boats were observed only at Guntersville Lake where they formed 10% of the sample.

The distribution of boats by length also differed between locations. The inland sites had a very low incidence of boats over 20 feet long (6.8% of the boats at Lake Havasu and 7.4% of the boats at Guntersville Lake). The northwest coastal sites had the greatest percentage of boats over 20 feet (55.1%). Lake Havasu and Guntersville had high percentages of boats under 16 feet (41.9% and 31.5%, respectively).

Table III-2 also shows the incidence of various activities. The percentage of boats fishing was remarkably similar (20-29%) for five of the locations sampled. The remaining two locations - Fort Lauderdale and Lake Havasu - showed a much smaller percentage of boats involved in fishing (4.3% and 1.2%, respectively). The percentage of boats involved in water skiing is probably underestimated due to cool and rainy weather conditions at the time of observation at many locations.

The people observed on board were categorized by age and sex. The majority of the people were adult males (56.3%). Adult females constituted only 21.6% of

the total sample. Children accounted for 12.9% of the sample, and teenagers for 9.2%. The proportion of children on board varied considerably as a function of location. Fewest children were observed at the northwest coastal and southeast coastal locations; in each case, children made up about 5% of the percent of the sample. At other locations, the percentage of women on board also varied considerably, from a low of 9.2% in the northwest coastal sample to a high of 28% at Lake Havasu (southwest inland). The proportion of women and children observed seemed to be related to weather conditions.

Rate of PFD Wear

The wear rates for PFDs based on all locations are shown in Table III- 3 . In these figures, each boater was weighted equally. To the extent that boater exposure by location, boat type, etc., does not correspond to the number of boaters actually sampled, these results could be slightly biased. The Wulfsberg and Lang report (Reference 7) was used to generate exposure weights for each of five geographical categories. A weighted estimate of the overall wear rate was then calculated. The weighted wear rate was 6.5%. This suggests that the unweighted wear rate of 7.1% (see Table III- 3) may be slightly overestimated. Since the exposure data are available only for very broad categories and ignore some important distinctions (such as inland vs. coastal waters), it is questionable whether weighting would improve the present estimates. The present data are, therefore, presented in unweighted form.

Selected differences in wear rate as a function of age and sex (see Table III- 3) were tested for significance using chi-square contingency tables. Wear rate was significantly greater for adult females than for adult males ($\chi^2 = 5.19$, $p<0.05$). The wear rate did not differ for teenage males as opposed to females or male versus female children. Wear rate did vary significantly as a function of age, however. The overall wear rates for adults, teenagers, and children were 2%, 8%, and 37%, respectively ($\chi^2 = 484.0$, $p<0.001$).

Table III- 3 also shows the rate of wear of the various types of PFDs by age and sex. The preponderance of adult males, if they wear any PFD, wear the Type III vest, but adult females wear Type IIs and Type III vests with almost equal frequency. This difference was highly significant ($\chi^2 = 16.7$, $p<0.001$). The type of PFD worn

also differed by age. Children were much more likely to wear Type II devices than Type III vests, but the opposite was true of adults ($\chi^2 = 45.5$, $p<0.001$).

Table III- 4 shows the rate of PFD wear by location, boat length and type, and activity. The southeast inland location (Guntersville Lake) showed a much higher rate than the others. A later sample was taken at another lake in the southeast (Smith Lake, Alabama) for verification. The wear rate was still high, but more in line with other locations (10.5%). The differences in wear rate by location suggest the following summary statements:

- Wear rate seems to be generally higher at inland and fresh water locations than at coastal areas.
- Wear rate tends to be higher in the midwest and west than along the eastern coast of the U.S.

PFD wear rate also varied significantly by boat type ($\chi^2 = 41.4$, $p<0.001$). Wear rate was lowest on large power craft, intermediate for smaller, open power craft, and highest for sailboats.

Table III- 4 also shows the rate of PFD wear as a function of boat length. Surprisingly, the percentage of people wearing PFDs was very similar for boats less than 16 feet long and those from 16 to 20 feet. However, wear rate was much lower in boats longer than 20 feet. The change in wear rate with length was highly significant ($\chi^2 = 16.2$, $p<0.001$). The difference in wear rate from boats less than 20 feet long to those greater than 20 feet would have been even greater if sailboats had not been included in the sample. The change in wear rate from boats less than 16 feet to the two larger categories was most pronounced for teenage males (13.7% vs. 2.2%).

The percentage of people wearing PFDs also changed with activity. The rate of PFD wear is lowest (5%) for fishing, intermediate (7.4%) for pleasure cruising and highest (13.9%) for skiing ($\chi^2 = 11.4$, $p<0.01$). It should be noted that the sample of skiers is made up entirely of people in the boat as opposed to on skis.

PFD Accessibility

Table III-5 shows the number of boats which met certain criteria of PFD accessibility. Coast Guard regulations specify that boats under 16 feet long shall have at least one Coast Guard approved Type I, II, III (wearable) or Type IV (throwable) PFD on board for each person. Boats 16 feet in length of greater must have one Type I, II, or III device on board for each person and in addition, one Type IV PFD. Types I, II and III must be readily accessible; Type IV must be immediately available. It is apparent that many boaters ignore the requirement to keep PFDs accessible. The picture is even gloomier if one considers only throwables (Type IV). Only 28% of the boats had at least one Type IV accessible.

Those locations which had the highest rates of wear also showed the highest accessibility. There was a strong association between wear rate and the proportion of boats having at least as many approved PFDs available as people on board (by location, $r_s = 0.679$, $p<0.05$).[1] However, this was not true for Type IVs. The location which showed the lowest percentage of boats with at least one Type IV accessible had the highest wear rate. In fact, the correlation between PFD wear and having at least one Type IV accessible for the seven locations was very near zero ($r_s=0.04$).[1]

The number of boats with at least one Type IV accessible varied considerably for different types of boats. The category of open rowboats, johnboats, etc., and the category of houseboats, pontoon boats and cabin cruisers were both high in comparison with the category of standard runabouts, bowriders, etc. These differences were highly significant ($\chi^2 = 20.98$, $p<0.005$). It may be that standard runabouts, bowriders, etc., are neither small and unstable enough to cause the owner to carry a throwable, nor large enough to make life rings seem appropriate.

Another significant relationship in Table III- 5 involves the number of boats with at least as many approved PFDs accessible as people on board. Small, lightweight boats show a much higher rate of PFD accessibility (54.7%) than do the larger power craft (14.1% and 19%). This relationship is highly significant ($\chi^2 = 39.57$, $p<0.005$). This difference may be due to the instability of small boats, or may reflect the fact that the smaller craft are open and have fewer "inaccessible" places for PFDs. A related difference appears with boat length. The percentage

---

[1] r_s is the Spearman rank correlation coefficient.

TABLE III-5. PERCENTAGE OF BOATS MEETING CERTAIN CRITERIA OF PFD ACCESSIBILITY BY BOAT TYPE, SIZE, AND ACTIVITY

	Percentage of boats which had accessible: At least one:		At least as many devices as people on board:	
BOAT TYPE	Approved PFD	Type IV (Throwable)	Approved PFD	Type I, II or III (Wearable)
House Pontoon Cabin Cruiser	53.5	39.4	14.1	6.2
Standard Runabout Bowrider High Performance Center Console Bass	57.5	20.7	19.0	11.0
Rowboat Johnboat Open Runabout Other < 16 Ft.	64.2	41.5	54.7	24.5
Sail	83.3	33.3	50.0	50.0
BOAT OVERALL LENGTH (Ft)				
< 16	58.1	29.6	32.4	16.4
16 - 20	60.2	21.8	21.8	13.3
> 20	53.0	35.1	14.6	6.6
ACTIVITY				
Fishing	62.4	33.6	32.0	13.6
Pleasure Cruising	54.4	25.6	19.3	12.3
Skiing	93.5	35.5	12.9	0.0
Other	33.3	16.7	22.2	9.7
ALL BOATS	57.6	28.0	22.2	12.0

TABLE III-6. NUMBER OF PFDS ACCESSIBLE AND PERCENTAGE OF THESE PFDS WORN BY LOCATION

	Type of PFD						
Location	Ski Belt	Type II Yoke[b]	Type III Vest	Type III Jacket	Number of Boats	% of People on Board w/Wearable PFD Accessible	% of People on Board With a PFD Accessible
NE Coastal	1 (0)[a]	52 (32.7)	9 (44.4)	0 -	141	14.3	28.2
NW Coastal	0 -	2 (0)	10 (90)	3 (100)	18	27.3	41.8
SW Coastal	2 (0)	58 (25.9)	13 (38.5)	4 (50)	110	21.6	31.7
SE Coastal	0 -	7 (0)	0 -	0 -	23	15.9	27.3
SW Inland	5 (40)	29 (48.3)	29 (10.3)	0 -	57	29.0	35.9
SE Inland	4 (50)	58 (39.7)	16 (87.5)	0 -	54	40.2	43.3
Great Lakes	2 (50)	61 (34.4)	9 (22.2)	0 -	87	26.5	44.5
TOTAL	14 (35.7)	267 (33.7)	86 (43.0)	7 (71.4)	490	23.8	35.2

[a] Figures in parentheses are the percentage of accessible PFDs worn; Those with no parentheses are the number of PFDs accessible.

[b] Predominately AK-1s.

NOTE: Any PFDs over and above the number of people on board a boat were not counted.

of boats with a sufficient number of approved PFDs accessible decreases as length increases, going from 32.4% for boats under 16 feet to 14.6% for boats over 20 feet long ($\chi^2 = 12.2$, $p<0.01$).

PFD accessibility also depends on activity. The percentage of boats with at least one approved PFD accessible is much higher for skiing than other activities ($\chi^2 = 11.16$, $p<0.005$). The percentage of boats with at least one Type IV accessible did not differ significantly for the various activities ($\chi^2 = 3.66$, $p>0.05$). Interestingly, the number of boats having sufficient approved PFDs on board was highest for fishing and lowest for skiing ($\chi^2 = 10.02$, $p<0.01$). These results suggest that skiers may tend to use PFDs only for skiing as opposed to general use on board the boat. Thus, skiers tend to have accessible only one or two PFDs, while fishermen are more likely to have a sufficient number of PFDs accessible for all the people aboard.

Table III-6 shows the number of PFDs accessible by type and the proportion of accessible PFDs which are worn. The top entry in each cell represents the number of PFDs accessible. The lower figures in parentheses are the percentages of accessible PFDs worn.

The percentage of accessible PFDs worn can be used as a rough measure of PFD wearability (which presumably reflects PFD comfort, attractiveness, etc.). From Table III- 6 it is evident that the wearability of various types of PFDs differed markedly with location. At the southeast inland location, Type III vests showed a higher wearability than did Type IIs or ski belts ($\chi^2 = 9.6$, $p<0.01$). However, the reverse was true at the southwest inland site ($\chi^2 = 10$, $p<0.01$). Wearability for Type IIs and vests* did not differ significantly at the Great Lakes, northeast coastal, and southwest coastal locations. At other locations, the number of accessible PFDs observed was too small to permit any conclusions. These results suggest that PFD wearability depends upon the conditions. The Type III vest is probably more comfortable under most conditions. However, under extremely hot conditions, such as those at the southwest inland location, the Type II with its smaller body coverage may be preferable.

Table III-6 also shows the percentage of people on board with a PFD accessible for each location. There is a high correlation between the percentage of people on board with a PFD accessible and the percentage of people wearing PFDs (see Table III-4) by location ($r_s = 0.89$, $p < 0.05$).

* Throughout this report "vest" is used in the usual sense, i.e., a sleeveless garmet covering the upper torso and shoulders. Some U.S. Coast Guard publications use "vest" to mean a Type II PFD.

Table III- 7 shows the tabulation of wearability and accessibility as a function of boat type, length, and activity. There were no significant differences in the wearability of various types of PFDs as a function of boat type. However, the percentage of people with a PFD accessible differed significantly with boat type ($\chi^2 = 41.17$, $p<0.005$). Sailboats and the category of small, lightweight boats showed roughly twice the PFD accessibility of larger power craft.

For boats under 16 feet and for boats from 16 to 20 feet, the wearability of Type III vests was greater than that of Type IIs. Data from these two categories of boat lengths were pooled. Using pooled figures, the wearability of vests (52%) was significantly greater than that of Type IIs (33%; $\chi^2 = 7.5$, $p<0.01$). However, for boats over 20 feet long, the wearability of Type IIs (36%) exceeded that of vests (15%; $\chi^2 = 3.22$, $0.10>p>0.05$). These results must be interpreted with caution. Large boats obviously have inaccessible places where PFDs can be stored out of sight of the observers. If a disproportionately large number of Type IIs are stored in these areas, the comparative wearability for Type IIs and vests on boats over 20 feet could be distorted. However, the reader will notice that the wearability of vest drops from 52% for boats less than 20 feet long to 15% for boats greater than 20 feet ($\chi^2 = 8.34$, $p<0.01$). Thus, there is an apparent change in wearability of vests with boat length.

The percentage of people on board with a PFD accessible was inversely related to boat length, going from a high of 40.7% for boats less than 16 feet long to 30.4% for boats greater than 20 feet ($\chi^2 = 9.72$, $p<0.01$).

For fishermen, the wearability of vests was dramatically higher than that of Type IIs ($\chi^2 = 10.36$, $p<0.01$). In contrast, wearability was higher for Type IIs than for vests for skiers ($\chi^2 = 4.35$, $p<0.05$). This result is particularly surprising when one considers that skiers were much more likely to have vests accessible than were fishermen. For skiers, 30% of the available PFDs were vests; but for fishermen only 18% of the accessible PFDs were vests. For pleasure cruising, wearability of yokes and vests did not differ significantly. Clearly, the wearability of various PFDs depends upon the activity in which the boater happens to be engaged. Further research will be required to specify the exact characteristics of each activity which influence wearability.

TABLE III-7. NUMBER OF PFDS ACCESSIBLE AND PERCENTAGE OF THESE PFDS WORN BY BOAT TYPE, LENGTH, AND ACTIVITY

Boat Type	Ski Belt	Type II Yoke[a]	Type III Vest	Type III Jacket	% of People on Board w/Wearable PFD Accessible	% of People on Board With a PFD Accessible
	Type of PFD					
Houseboat Pontoon Cabin Cruiser	2 (0)	55 (29.1)	12 (25)	0 -	16.2	29.7
Standard Runabout Bowrider High Performance Center Console Bass	11 (36.7)	180 (37.2)	66 (42.4)	2 (0)	25.8	34.4
Rowboat Johnboat Open Runabout Other < 16 Ft	1 (100)	30 (23.3)	3 (33.3)	2 (100)	30.5	59.3
Sail	0 -	1 (0)	5 (100)	3 (100)	56.3	62.5
Boat Length (Ft)						
< 16	3 (33.3)	70 (35.7)	11 (54.5)	2 (100)	24.5	40.7
16 - 20	8 (37.5)	139 (31.7)	55 (50.9)	1 (0)	28.3	35.8
> 20	3 (33.3)	58 (36.2)	20 (15)	4 (75)	16.9	30.4
Activity						
Fishing	1 (100)	48 (12.5)	11 (63.6)	1 (0)	23.3	47.3
Pleasure Cruising	6 (33.3)	193 (36.3)	56 (39.3)	6 (83.3)	22.9	31.7
Skiing	7 (28.6)	25 (56)	14 (21.4)	0 -	34.6	45.1
Other	0 -	1 (0)	5 (100)	0 -	15.8	21.1

NOTE: Any PFD's over and above the number of people on board a boat were not counted.

TABLE III-8. ESTIMATED NUMBER OF PFDS ACCESSIBLE OR ON BOARD PER BOAT

Measure	Ski Belt	Type II Yoke[a]	Type III Vest	Type III Jacket	Type IV Throwables
PFD's Accessible					
Observations *	.015	.506	.092	.012	.559
Interviews	.182	2.939	.030	0.000	.667
PFD's On Board					
Interviews	.303	6.303	1.000	.394	1.515

* These figures are the averages for the same three locations for which interview data was available.

[a]Predominately AK-1s.

The percentage of people on board with a PFD accessible also differed as a function of activity. Fishing and skiing showed highest accessibility while people pleasure cruising were less likely to have a PFD accessible ($\chi^2 = 28.45$, $p<0.005$).

Table III-6 also shows the relative accessibility of Type IIs and vests. Overall, Type IIs made up 71.4% of the accessible wearable PFDs; vests accounted for only 23%. Lake Havasu (southwest inland) had the highest accessibility of vests (46% of the wearable PFDs), while the Great Lakes and northeast coastal locations had the smallest percentage of vests (14.5% and 12.5%, respectively).

Table III-7 shows the variation in relative accessibility as a function of boat type. Vests made up the largest portion of the PFD population for the category of standard runabouts, etc. Small, lightweight boats had the lowest availability of vests, and house, pontoon boats and cabin cruisers were intermediate ($\chi^2 = 6.51$, $p<0.05$). Relative accessibility did not differ significantly with activity.

Interview Data

Table III-8 summarizes the reported number of PFDs on board and the number of PFDs which interview subjects reportedly keep accessible on a normal outing. It should be emphasized that the interview data are all self-reports and therefore, subject to distortion. For example, interviewees report that on the average nearly three Type IIs are kept accessible per boat. However, observations of boats reveal only 50 Type IIs accessible per 100 boats. The number of PFDs reportedly on board may be similarly distorted. If the reported number of PFDs aboard is taken at face value, then only a small proportion of PFDs are kept accessible. For vests and Type IIs, for example, the number of accessible PFDs is only 1/11-1/12 of those reportedly on board.

Table III-9 shows reported preference. The solid construction foam ski vest was ranked highest. The AK-1 ranked second in preference. The high ranking given AK-1s may be due to the subjects' lack of experience with other types of PFDs.

TABLE III-9 . PFD PREFERENCE

Rank (1=Most Preferred)	PFD Type
1	Ski vest, solid construction, belted (Type III)
2	AK-1, (Type II)
3	Hinged vest with zipper (Type III)
4	Buoyant jacket (Type III)
5	Kapok-filled Type I vest
6	Inflatable jacket (Not approved)
7	Vinyl covered foam yoke (Type I)
8	Featherlight (Type III)

3.3 Conclusions

The present study assessed PFD accessibility and wear by directly observing recreational boaters underway in seven regions of the Continental United States. The overall percentage of boaters wearing PFDs was very low (7.1%). The low wear rate is not surprising in view of boaters' attitudes about PFDs. Interviews indicated that most boaters believe that PFD wear is necessary only under extreme conditions (e.g., rough water), for children, and in a few cases for non-swimmers. As yet (1975), boating safety courses and Coast Guard publications and films had done little to combat these attitudes in those that were interviewed.

An additional reason for the low wear rate may be PFD discomfort and expense. Boaters frequently complained that Type II PFDs are too bulky. On the other hand, Type III devices are too expensive, according to boaters' reports.

A third factor which may contribute to the low wear rate is motivation. The boater on a typical outing probably does not anticipate entering the water. In those activities where entering the water is more likely, PFD wear is higher. Sailboats and boats involved in skiing show exceptionally high rates of wear.

One would also expect the PFD wear rate to be higher in smaller, less stable boats. This prediction was only partially supported. Wear rate was inversely related to

boat length, but the differences were not dramatic. On the other hand, the category of "rowboats, johnboats, etc." which are often under 16 feet showed a slightly <u>lower</u> wear rate than the category of standard runabouts, bowriders, etc.

The fact that wear rate differed widely between locations (a high of 22.5% vs. a low of 3.3%) suggests that PFD-wearing behavior may be reasonably malleable.

The accessibility data show that a sizeable proportion of the boats over 16 feet long (27%) do not have at least one Type IV device accessible as required by the Coast Guard. The data also show that 42.4% of the boats observed had no approved PFD of any kind accessible.

Although PFD accessibility in general is correlated with wear, availability of Type IV devices was not associated with wear. This result suggests that some boaters who do not wear PFDs nonetheless keep a Type IV accessible. If this is the case, it may prove easier to increase PFD accessibility than wear.

Comparing Tables III-4 and III-7, it is evident that PFD wear is strongly associated with the percentage of people on board with an approved PFD accessible. Some noticeable exceptions to this rule are the activity of fishing and the category of "rowboats, johnboats, etc." These two categories are near or below the mean on PFD wear, but well above the mean on PFD accessibility. Of course, these two categories overlap considerably, i.e., many fishermen use small, lightweight boats. The reason for the discrepancy between the levels of wear and availability for these categories may be related to the necessity for freedom of movement in fishing. This would make wear of the standard Type II, which constitutes most of the PFD population, low. At the same time, fishermen often use small, relatively unstable boats and must execute more movements in the boat, which might lead them to keep PFDs highly accessible. Incidently, the present argument also suggests that wearability of vests should be much higher than that of Type IIs for fishermen. This was indeed the case as discussed below.

The most important conclusion about PFD wearability is that it is relative to the conditions. The results show that wearability of vests is greater than that of Type IIs for fishermen, but the opposite is true for skiers. Similarly, in hot locations like Lake Havasu, wearability of Type IIs was greater than that of vests, while in more temperate climates like Guntersville Lake, the reverse occurred. The

relative wearability of Type IIs and vests also changed as a function of boat length. The results suggest that many variables influence wearability, and that the relative weight of these variables depends on the conditions.

As expected, the results show that most of the accessible PFDs were Type IIs as opposed to Type III vests. Vests were particularly scarce on boats less than 16 feet long, on small, lightweight boats, and in certain locations. Vests were frequent on boats involved in skiing, and at the Lake Havasu location. The fact that size and type of boat influences the accessibility of vests may reflect the high cost of these PFDs. The overall low frequency of vests relative to Type IIs could also be due in part to boat dealers' retailing practices. Dealers generally sell boats as a complete system including a "Coast Guard Safety Package" (i.e., PFDs). In order to keep the price as low as possible, dealers normally include only Type II PFDs. An educational program in this area could encourage dealers to offer alternative safety packages.

The foregoing results have amply demonstrated the feasibility and value of a direct observational approach to PFD wearability and use. This technique avoids the biases inherent in survey and self-report methods. The method of direct observation used in this study revealed unexpected relationships and interactions of PFD use with other variables which probably would not have been discovered through a survey approach.

4.0 WEARABILITY/ACCESSIBILITY STUDY

4.1 Method

Thirty-six adults who were currently active boaters each evaluated from one to six PFDs for a total of 185 PFD evaluations. The study was conducted in January and February 1977. Twenty-nine of the participants were from south Florida. Of the remaining participants, three resided in North Alabama and four were from the Washington, D.C., area. Thirty-two participants were acquaintances of Wyle or USCG personnel; four were Wyle or USCG personnel whose work did not directly involve them in the project. Since data collection was limited to the winter months and most of the sample was from south Florida, the estimates of wearability and accessibility in this study are not necessarily representative of recreational boating nationwide. The primary purpose of this study was to demonstrate the feasibility of methods for measuring wearability and accessibility.

The 106 PFDs used in the present study represented most of the major types of PFDs available world-wide. In all, 67 different models were used (see Figure III-2 and Table III-13). The greatest possible variety of PFDs was used to insure that the wearability and accessibility indices developed in this work would have the widest possible applicability to devices now and in the future.

In order to minimize any bias in the evaluations, each participant was given devices which differed as widely as possible in their design and functional characteristics. All but five of the participants evaluated three or more PFDs. As nearly as possible, each of these participants was given an equal number of PFDs for evaluation from each of the three categories shown below:

- Hybrids, inflatables, flotation jackets, and ski belts.
- Vest* -style devices (all inherently buoyant)(mostly Type IIIs).
- Throwables and devices whose wearability would be expected to be low (all inherently buoyant)(most Type I, II, and IV devices).

Each participant was allowed to choose one USCG approved PFD to keep as an incentive for participation in the study. Participants received no other form of compensation.

---

* Throughout this report "vest" is used in the usual sense, i.e., a sleeveless garmet covering the upper torso and shoulders. Some U.S. Coast Guard publications use "vest" to mean a Type II PFD.

261, 262*

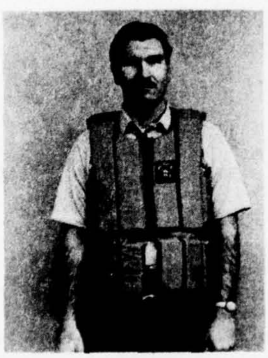
295 (366)

335

314, 316

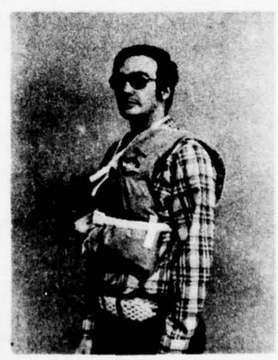
200, 201, 204, 206

115, 116 (367)



196, 197, 198

336



300, 329

* The numbers below each photograph are "Wyle numbers" assigned to each PFD. These PFDs are also described in Table III-13. Numbers in parentheses represent PFDs similar, but not identical, to the photographs shown.

FIGURE III-2. PFDS EVALUATED IN THE WEARABILITY/ACCESSIBILITY STUDY

284, 285, 286, 287

348, 274

349, 305, 306

302

301

082, 084, 303

304

246, 247, 249

102

FIGURE III-2. (continued)

186

327

331, 332

137, 138

298

326

345, 005

330

333, 334

FIGURE III-2. (continued)

037 (998)

176, 177, 178, 179
(182, 180, 183,
123, 058)

293 (294)

291 (292)

337

322, 323

012 (218, 276)

169, 173

307

FIGURE III-2. (continued)

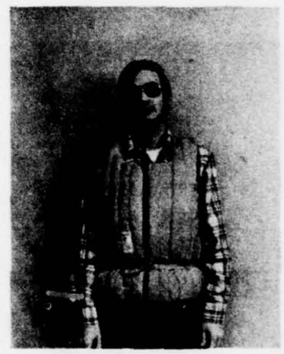
146

155

142

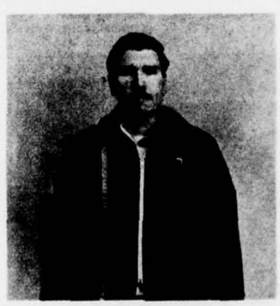
296

328



149

278



139 (370, 371)

195

FIGURE III-2. (continued)

152

277

154

275

161, 162

166, 168

325

251, 252

130, 132, 255,
193. 133 (157)

FIGURE III-2. (continued)

253, 192

342, 343

341

340

338 (339)

344

FIGURE III-2. (concluded)

Participants were instructed to take each PFD to be evaluated along on at least one boat outing and to evaluate the PFD immediately after the outing. They were asked to try the PFD on, if it was a wearable device, during the outing and thereafter to treat the device as they would normally. Each participant was carefully instructed that they should not wear or use the device simply because it was part of a research study. They were told that one of the objectives of the research was to measure how much of the time boaters actually wore the candidate PFD. Additional written instructions were distributed to the participants and were reviewed verbally by the experimenter with each participant (see Figure III-3). In addition, a consent form and cautionary message was used. The experimenter provided each participant with two copies of the consent form. The form was read aloud to the participant who signed and returned one copy. The second copy was left with the participant.

Four interview or data forms were used (see Figure III-3). Form 1 concerned the boater, his activities, type of boat, and customary rate of PFD wear. Form 1 was filled out by the experimenter in the company of the participant. Form 1A contains 23 questions relating to the participants attitudes about PFDs and boating safety. Form 1A was filled out by the participant during the initial interview with the experimenter. Form 2 is a log of actual PFD use time during an outing. It contains a record of situational variables characterizing the outing (e.g., weather, activity, etc.) and estimates of the amount of time the PFD was worn and kept accessible. Form 3 contains 26 questions about the properties of the candidate PFD. The questions on Form 3 deal with seven dimensions which characterize PFD properties or the boater's relationship to his/her PFD. The questions were selected because they seemed to be highly related to wearability or accessibility in pilot studies (see Doll, et al., 1976). The seven dimensions are:

1. PFD appearance.
2. PFD comfort.
3. The compatibility of the PFD with the boater's activities (i.e., whether it interferes with or facilitates his/her activities; whether it has some use other than flotation which he/she considers valuable).
4. Image (how the boater feels about wearing the PFD and how he/she regards others who wear or use the PFD).
5. Perceived effectiveness and reliability of the PFD.
6. The boater's expression of his/her intention to wear the PFD in both normal and emergency conditions.

INFORMATION FOR PARTICIPANTS

This study conducted by Wyle Laboratories is an important part of the U. S. Coast Guard's research program on personal flotation devices (PFDs). As you know, the Coast Guard regulates PFDs through its testing and approval program and by prescribing PFD carriage requirements. Under current regulations, only certain limited types of PFD designs are eligible for approval. Some of the types of PFDs now approved are bulky, uncomfortable, or unattractive. Research shows that only a small percentage of boaters routinely wear or use the currently approved PFDs. The low wear and use rates seriously compromise the capability of PFDs to save lives. If a PFD is not worn or readily accessible when an accident occurs, it cannot help. The objective of the PFD research program is to develop more flexible test procedures, so that more wearable and effective devices can be developed by the PFD industry.

The purpose of this study is to determine what factors influence the wearability and accessibility of PFDs. You will be provided with six different types of PFDs to evaluate. We are using the widest possible range of PFDs, including inflatable devices and some devices which are not designed to be worn. We ask that you try out each PFD provided on a separate boat outing. When you return, please fill out one copy of FORM 2 - PFD USE LOG and one copy of FORM 3 - PFD OPINION QUESTIONNAIRE for the PFD. Please try to use and evaluate the PFDs provided as soon as possible so that we can collect them and pass them on to other participants. We will arrange a time with you (probably by telephone) at which we will pick up the PFDs and evaluation forms.

We will also ask you questions concerning your personal attitudes and opinions. The purpose of these questions is to determine what personal characteristics are related to PFD wear and use. This information should be helpful in developing educational programs to promote PFD use. Your answers will not be identified by name and results will be reported only as overall statistics for the entire group or boaters participating. Please fill out all the forms as completely as possible. If you have any questions concerning this study or the operation of a PFD, please call me at the following toll free number: 800/633-2085 or 86.

Theodore J. Doll

Theodore J. Doll, Ph.D.
Senior Research Psychologist

FIGURE III-3. WRITTEN INSTRUCTIONS AND DATA FORMS FOR WEARABILITY/ACCESSIBILITY STUDY

INITIAL INTERVIEW — FORM 1

PFD WEARABILITY RESEARCH — PHASE II
CONDUCTED BY WYLE LABORATORIES FOR THE UNITED STATES COAST GUARD

Respondent Number *V1** ____________ Date ____/____/____ (Month) (Day) (Year)

Name ____________ Age *V3* ____ Sex *V4* ____ (M/F)

Address ____________ (Street and Number, City, State, Zipcode) Phone ____________

Formal Boating Safety Courses You Have Completed: *V5* None *V6* USCG Auxiliary *V7* U.S. Power Squadron

V8 American Red Cross *V9* State Course *V10* ____________ Other (Specify)

V11 Hours of Boating Experience: ____ < 20 ____ 20-100 ____ 100-500 ____ > 500

V12 Location of Principal Boating Activities ____________ (Specify whether ocean, lake, river, bay, harbor, etc.)

V13 Make, Model and Type of Boat Used ____________

____________ Length *V14* ft HP *V15*

Principal Activities (Check as many as apply): *V16* Fishing *V17* Hunting *V18* Canoeing or Kayaking *V19* Water Skiing

V20 Skin Diving *V21* Scuba Diving *V22* Swimming *V23* Camping *V24* Sailing *V25* Pleasure Cruising

V26 Racing *V27* Beach Combing/Exploring Islands *V28* ____________ Other (Specify)

What types of PFDs do you currently use on boat outings? (Please fill in one of the following boxes for each type of PFD you typically use.)

Manufacturer ____________	Manufacturer ____________
Model ____________	Model ____________
Style (Check one) ____ Vest	Style (Check one) ____ Vest
____ Jacket	____ Jacket
____ Belt	____ Belt
____ Bib/Yoke	____ Bib/Yoke
Color/Pattern ____________	Color/Pattern ____________
Coast Guard Type ____________	Coast Guard Type ____________
Number Aboard ____________	Number Aboard ____________
Location During Outings: (Check applicable blanks)	Location During Outings: (Check applicable blanks)
____ Worn by you ____ Worn by another person	____ Worn by you ____ Worn by another person
____ Kept in open place, e.g., in cockpit, on bridge	____ Kept in open place, e.g., in cockpit, on bridge
____ Kept in sheltered but not completely enclosed place	____ Kept in sheltered but not completely enclosed place
____ Kept in cabin, locker, or other enclosed place	____ Kept in cabin, locker, or other enclosed place

(Continued on reverse side)

* *Variable numbers (V1, V2, etc.) shown in italics are for computer coding purposes and did not appear on the original data forms.*

FIGURE III-3. (continued)

Manufacturer ____________________
Model ____________________
Style (Check one) ___ Vest
___ Jacket
___ Belt
___ Bib/Yoke
Color/Pattern ____________________
Coast Guard Type ____________
Number Aboard ____________
Location During Outings: (Check applicable blanks)
___ Worn by you ___ Worn by another person
___ Kept in open place, e.g., in cockpit, on bridge
___ Kept in sheltered but not completely enclosed place
___ Kept in cabin, locker, or other enclosed place

Manufacturer ____________________
Model ____________________
Style (Check one) ___ Vest
___ Jacket
___ Belt
___ Bib/Yoke
Color/Pattern ____________________
Coast Guard Type ____________
Number Aboard ____________
Location During Outings: (Check applicable blanks)
___ Worn by you ___ Worn by another person
___ Kept in open place, e.g., in cockpit, on bridge
___ Kept in sheltered but not completely enclosed place
___ Kept in cabin, locker, or other enclosed place

V29 How often do you personally wear a PFD on boat outings? (Please check one alternative below.)

Codes

01 I wear a PFD almost continuously (over 75% of the time)

02 I wear a PFD most (50-75%) of the time

03 I wear a PFD only part (10-50%) of the time

04 I wear a PFD only a small fraction (1-10%) of the time

05 I almost never wear a PFD

FIGURE III-3. (continued)

RESPONDENT OPINIONS — FORM 1A

PFD WEARABILITY RESEARCH — PHASE II

CONDUCTED BY WYLE LABORATORIES FOR THE UNITED STATES COAST GUARD

INSTRUCTIONS: This questionnaire consists of four parts. Part I concerns your attitudes about PFDs related matters. Parts II, III, and IV concern your personal attitudes about yourself. Your answers will not be identified by name. Results will be reported only as overall statistics for the entire group of boaters participating.

Respondent Number ______________________

PART I — Below you see a list of statements about PFDs and related matters. Please read each statement carefully. Circle one of the numbers to the right to indicate how strongly you agree or disagree with the statement. Use only the numbers shown and answer every item.

		Disagree Strongly	Disagree Moderately	Disagree Slightly	Agree Slightly	Agree Moderately	Agree Strongly
730 1.	I always keep a PFD out in the open aboard my boat so it will be accessible in case of emergency.	1	2	3	4	5	6
731 2.	I sometimes don a PFD when I see rough water or a storm approaching while out boating.	1	2	3	4	5	6
732 3.	Most PFDs will keep the wearer's mouth and nose clear of the water if he becomes unconscious while in the water.	1	2	3	4	5	6
733 4.	If I were thrown into the water in a boating accident, I would need some help to stay afloat.	1	2	3	4	5	6
734 5.	A responsible boater is more likely to wear a PFD than is the careless boater.	1	2	3	4	5	6
735 6.	In a genuine boating emergency, I'd want to be wearing a PFD.	1	2	3	4	5	6
736 7.	Adventurous boaters wouldn't wear a PFD.	1	2	3	4	5	6
737 8.	If not carefully maintained and checked, PFDs may deteriorate quickly to the point where they would malfunction.	1	2	3	4	5	6
738 9.	If passengers saw PFDs lying around a boat, they would probably feel safer.	1	2	3	4	5	6
739 10.	Relaxed, casual boaters would wear a PFD.	1	2	3	4	5	6
V40 11.	A PFD makes the wearer look tense and uncomfortable.	1	2	3	4	5	6

FIGURE III-3. (continued)

			Disagree Strongly	Disagree Moderately	Disagree Slightly	Agree Slightly	Agree Moderately	Agree Strongly
V41	12.	I make sure the PFDs are readily accessible when I encounter rough water or see an approaching storm.	1	2	3	4	5	6
V42	13.	Most PFDs are not effective in rough water.	1	2	3	4	5	6
V43	14.	PFDs are emergency equipment only and are not meant to be worn all the time.	1	2	3	4	5	6
V44	15.	I am able to tread water or swim well enough to stay afloat for at least 10 or 15 minutes without a PFD.	1	2	3	4	5	6
V45	16.	In a genuine boating emergency, I'd be better off if I weren't wearing a PFD.	1	2	3	4	5	6
V46	17.	A good swimmer really doesn't need a PFD in a boating emergency.	1	2	3	4	5	6
V47	18.	I wear a PFD most of the time while boating.	1	2	3	4	5	6
V48	19.	Boaters who wear a PFD look confident.	1	2	3	4	5	6
V49	20.	The expert boater would probably not wear a PFD under normal conditions.	1	2	3	4	5	6
V50	21.	People who wear PFDs routinely are probably fearful of the water.	1	2	3	4	5	6
V51	22.	If I kept PFDs lying out in the open aboard my boat, experienced boaters or friends would probably think I was being over-cautious.	1	2	3	4	5	6
V52	23.	I feel a little afraid when I'm in a small boat far from shore.	1	2	3	4	5	6

FIGURE III-3. (continued)

PFD USE LOG — FORM 2

PFD WEARABILITY RESEARCH — PHASE II

CONDUCTED BY WYLE LABORATORIES FOR THE UNITED STATES COAST GUARD

INSTRUCTIONS: Please fill out this form after each boat outing for which you had a Wyle-supplied PFD on board, regardless of whether you actually used the PFD or not. If you have more than one Wyle-supplied PFD aboard, fill out a separate copy of this form for each PFD.

IDENTIFY THE PFD TO WHICH THIS FORM APPLIES:

Manufacturer ______________________ Model ______________________

V53 Style (Check one) 01 Vest 02 Jacket 03 Belt 04 Bib/Yoke/Collar

Color ______________________ Wyle Number V2

GENERAL INFORMATION:

Your Name ______________________ Date of Outing ______________________ (Day) (Month) (Year)

* Approximate Duration of Outing ________ hrs (Include only time on the water)

Your Principal Activities on This Outing (Check as many as apply): V54 Fishing V55 Canoeing or Kayaking

V56 Skin Diving V57 Scuba Diving V58 Swimming V59 Camping V60 Sailing V61 Water Skiing

V62 Pleasure Cruising V63 Racing V64 Hunting V65 ______________________ Other (Specify)

The Weather and Water Conditions on This Outing:

V66 Water Conditions: 01 Calm 02 Choppy 03 Rough 04 Swift Current 04 White Water

05 Occasionally Choppy or Rough

V67 Approximate Air Temperature ________ °F

V68 Weather: 01 Sunny 02 Cloudy 03 Fog/Haze 04 Rain

V69 Wind: 01 Calm 02 Moderate 03 Strong

INDICATE WHERE THE PFD WAS KEPT DURING THE OUTING:

Please estimate how long the PFD was used or kept in each of the ways listed below:

Worn by you .... ________ hrs } Sum = V70

Worn by another person .... ________ hrs }

Kept in an open place, e.g., cockpit, on bridge .... ________ hrs V71

Kept in sheltered but not completely enclosed place .... ________ hrs } Sum = V72

Kept in cabin, locker or other enclosed place .... ________ hrs }

TOTAL (Please check to make sure this equals the duration of outing (*) shown above) ________ hrs V73

V74 **INDICATE HOW MUCH OF THE TIME YOU WORE THE PFD:**

Please check the one statement below which best describes how long you used the PFD:

01 I wore the PFD almost continuously (over 75% of the time) during this outing.

02 I wore the PFD most (50-75%) of the time on this outing.

03 I wore the PFD only part (10-50%) of the time on this outing.

04 I wore the PFD only a small fraction (1-10%) of the time on this outing.

05 I didn't wear the PFD at all, or just tried it on and then took it off right away.

NOTE: NV1 = Proportion of time the candidate PFD was worn = V70/V73
NV8 = Proportion of time the candidate PFD was kept accessible or worn = (V70 + V71)/V73

FIGURE III-3. (continued)

PFD OPINION QUESTIONNAIRE – FORM 3

PFD WEARABILITY RESEARCH – PHASE II
CONDUCTED BY WYLE LABORATORIES FOR THE UNITED STATES COAST GUARD

INSTRUCTIONS: Please fill out this form once for each Wyle-supplied PFD. Read each statement carefully and circle one of the numbers to the right to indicate your extent of agreement. Use only the numbers shown and answer every statement. If the statement does not seem applicable to the PFD, answer "strongly disagree."

Name ______________________

Address ______________________
(Street and Number)

____
(City, State, Zipcode)

Date ______________________
(Day) (Month) (Year)

PFD IDENTIFICATION:

Manufacturer ______________________

Model ______________________

Style (check one) _______ Vest

_______ Jacket

_______ Belt

_______ Bib/Yoke/Collar

Color ______________________

Wyle Number ______________________

			Disagree Strongly	Disagree Moderately	Disagree Slightly	Agree Slightly	Agree Moderately	Agree Strongly
V75	1.	This PFD tends to ride up or otherwise be uncomfortable when the wearer is in a sitting or reclining position.	1	2	3	4	5	6
V76	2.	This PFD makes the wearer look tense and uncomfortable.	1	2	3	4	5	6
V77	3.	This PFD would help keep the wearer dry in rain or spray.	1	2	3	4	5	6
V78	4.	Responsible boaters would be willing to wear this PFD routinely while boating.	1	2	3	4	5	6
V79	5.	This PFD is easy to put on and fasten.	1	2	3	4	5	6
V80	6.	I like the cut and shape of this PFD.	1	2	3	4	5	6
V81	7.	If I wore a PFD of this type under normal conditions, friends would probably think I was being over-cautious.	1	2	3	4	5	6
V82	8.	This PFD does not restrict my movement or get in my way.	1	2	3	4	5	6
V83	9.	If not carefully maintained and checked, this PFD might deteriorate quickly to the point where it would malfunction.	1	2	3	4	5	6
V84	10.	I would wear this PFD only in very rough conditions.	1	2	3	4	5	6
V85	11.	In a genuine boating emergency, I'd want to be wearing or using a PFD of this type.	1	2	3	4	5	6
V86	12.	This PFD can be conveniently used as a cushion or pillow to sit or recline on.	1	2	3	4	5	6
V87	13.	This PFD would help keep the wearer warm in cool weather.	1	2	3	4	5	6
V88	14.	Adventurous boaters wouldn't wear this PFD.	1	2	3	4	5	6

FIGURE III-3. (continued)

			Disagree Strongly	Disagree Moderately	Disagree Slightly	Agree Slightly	Agree Moderately	Agree Strongly
V89	15.	This PFD looks awkward and unattractive on most people.	1	2	3	4	5	6
V90	16.	The color of the PFD matches my boat and/or the clothes I usually wear boating.	1	2	3	4	5	6
V91	17.	This PFD fits snugly all around, but not too tightly.	1	2	3	4	5	6
V92	18.	I like this PFD because it's reasonably compact or flat.	1	2	3	4	5	6
V93	19.	This PFD looks like it would be highly effective in keeping the wearer's head out of the water so he could breathe.	1	2	3	4	5	6
V94	20.	This PFD is not excessively hot or sweaty in warm weather.	1	2	3	4	5	6
V95	21.	This PFD does not rub, scrape, or pinch the wearer's skin.	1	2	3	4	5	6
V96	22.	This PFD does not detract from the appearance of the person who wears it.	1	2	3	4	5	6
V97	23.	The expert boater would probably not wear this PFD under normal conditions.	1	2	3	4	5	6
V98	24.	This PFD would be reasonably comfortable to wear for hours at a time.	1	2	3	4	5	6
V99	25.	This PFD provides good protection from impact with the water.	1	2	3	4	5	6
V100	26.	This PFD would not prevent the wearer from getting a suntan.	1	2	3	4	5	6
V101	27.	This PFD looks like it would work well even in rough water.	1	2	3	4	5	6
V102	28.	The pockets on this PFD are useful and convenient.	1	2	3	4	5	6
V103	29.	If I owned this PFD, I would wear it more than I do the best of my current PFDs.	1	2	3	4	5	6
V104	30.	This PFD feels bulky when worn.	1	2	3	4	5	6
V105	31.	If I had this type of PFD aboard my boat, I would keep it out in the open so it would be accessible in case of an emergency.	1	2	3	4	5	6
V106	32.	If I had a PFD of this type, I would wear it most of the time while boating.	1	2	3	4	5	6
V107	33.	Boaters who wear this PFD look confident.	1	2	3	4	5	6
V108	34.	The color and/or pattern of the covering on this PFD is attractive. (Rate preferred side if reversible.)	1	2	3	4	5	6
V109	35.	This PFD is useful for my boating activities in addition to providing flotation in the event of an accident.	1	2	3	4	5	6
V110	36.	Relaxed, casual boaters would wear this PFD.	1	2	3	4	5	6

FIGURE III-3. (concluded)

7. The boater's expression of intention to keep the PFD accessible while boating.

Each participant filled out one copy of Form 2 and one copy of Form 3 for each PFD evaluated.

The data were coded into computer readable form and verified using the same procedure applied to ARM data (see Section VI of this report). Data reduction and statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) on the Cybernet computer system.

4.2 Characteristics of the Sample

This section discusses the situational variables which describe the conditions under which PFDs were evaluated in the present study. It is important to study the characteristics of the sample in order to know in which respects it is, or is not, representative of recreational boating in the United States. It should be noted that the primary purpose of this study was to demonstrate the feasibility of the present methods for measuring wearability and accessibility. Since data collection was limited to winter months, most of the sample was from south Florida. It is anticipated that the sample will be augmented in future work. The present section discusses characteristics of the boaters who evaluated PFDs, their attitudes and activities, their boats, and environmental conditions.

The distributions of PFD evaluations by the age and sex of the respondent are shown at the top of Table III-10. The present sample is older, contains more females, and more boaters who have completed a formal boating safety course than the reference sources. It should be noted, however, that the Wulfsberg and Lang (1974) and Bryk and Schupack (1973) data were collected four to five years prior to the present sample. Some of the demographic characteristics of the boating population may have changed in the interim period. When the present sample is augmented, the newly conducted Nationwide Boating Survey (results not available at this writing) and the ARM sample should be used as reference sources.

Table III-10 also shows the distribution of evaluations by boating activity. Note that the reference sources differ radically. A part of this difference may be due to the fact that ARM is a sample of boaters involved in accidents, whereas

TABLE III-10. CHARACTERISTICS OF THE BOATERS, THEIR BOATS, AND ACTIVITIES IN THE WEARABILITY STUDY

AGE IN YEARS	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF BOAT OPERATORS 20 YEARS OR OLDER FROM NBS[a]
30 or less	16	9	34
31 - 40	58	34	23
41 - 50	44	26	21
51 - 60	30	18	13
Over 60	23	13	9
Total Known	171	100	100
Unknown	8	-	-

SEX	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF BOAT OPERATORS 20 YEARS OR OLDER FROM NBS[a]	PERCENT OF PEOPLE IN BOATING ACCIDENTS FROM ARM	PERCENT OF OPERATORS FROM NSC[b]
Male	122	58	77	79	97
Female	57	32	23	21	3
Total	179	100	100	100	100

BOATING SAFETY COURSES COMPLETED	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF OPERATORS INVOLVED IN ACCIDENTS FOR WHOM FORMAL INSTRUCTION WAS KNOWN - FROM CG-357 FOR 1976	PERCENT OF PRIMARY OPERATORS FROM NBS[a]	PERCENT OF OPERATORS FROM NSC[b]
None	56	31	55	74.3	63
One or More	122	69	45	25.7	37
Total Known	178	100	100	100.0	100
Unknown	1	-	-	-	-

BOATING ACTIVITY	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF PEOPLE IN BOATING ACCIDENTS FROM ARM	NUMBER OF OPERATORS REPORTING THIS AS THEIR PRIMARY ACTIVITY FROM NSC[b]
Pleasure Cruising	81			
Sailing	20	66.9	74.4	25.0
Canoeing/Kayaking	16			
Fishing	49	28.0	13.7	55.9
Water Skiing	6	3.4	7.9	17.7
Swimming, Skin Diving	1	0.6	0.1	-
Hunting	0	0	0.5	0.5
Racing	0	0	3.4	0.8
Scuba Diving	2	1.1	-	-
Camping	0	0	-	-
Total Known Excluding "Other"	175	100.0	100.0	99.9

[a] Wulfsberg, R. M. & Lang, D. A., Recreational Boating in the Continental United States in 1973: The Nationwide Boating Survey. USCG report number 745103, Washington, D. C.

[b] Bryk, J. A. & Schupack, S. A., Boating Safety: The Use of Personal Flotation Devices. National Safety Council, September, 1974.

TABLE III-10. CHARACTERISTICS OF THE BOATERS, THEIR BOATS, AND ACTIVITIES IN THE WEARABILITY STUDY (concluded)

BOAT TYPE	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF PEOPLE IN ACCIDENTS FROM ARM (BASED ON USCG YEAR END DATA)
Open Manual	0	0	1.9
Open Power	60	34.3	55.7
Cabin/Houseboat	52	29.7	24.1
Sail	44	25.1	13.5
Canoe/Kayak	18	10.3	1.9
Other	1	0.6	2.8
Total Known	175	100.0	100.0
Unknown	4	-	-

OVERALL BOAT LENGTH (FEET)	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF PEOPLE IN ACCIDENTS FROM ARM (BASED ON USCG YEAR END DATA)
< 16	18	11.3	23.2
16 - 20	51	32.1	36.7
20 - 26	11	6.9	19.4
> 26	79	49.7	20.7
Total Known	159	100.0	100.0
Unknown	20	-	-

LOCATION OF PRINCIPAL BOATING ACTIVITIES	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS	PERCENT OF PEOPLE IN BOATING ACCIDENTS FROM ARM	PERCENT OF VESSELS IN ACCIDENTS FROM CG-357 FOR 1976
River, Creek	1	0.6	27.7	26.7
Small Lake	18	10.4	39.5	39.6
Great Lakes	0	0	4.7	3.0
Coastal Waters, Waterway, Harbor, Bay, Inlet, Ocean, Gulf	154	89.0	28.1	30.3
Other	0	0	0	0.3
Total Known	173	100.0	100.0	99.9
Unknown	6	-	-	-

HOURS OF BOATING EXPERIENCE	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS
< 20	0	0
20 - 100	7	4
100 - 500	24	13
Over 500	147	83
Total Known	178	100
Unknown	1	-

CUSTOMARY RATE OF PFD WEAR (VARIABLE 29)	NUMBER OF PFD EVALUATIONS	PERCENT OF PFD EVALUATIONS
Almost Continuously (over 75% of the time)	18	10.1
Most of the time (50-75%)	6	3.4
Only Part of the time (10-50%)	46	25.8
Small fraction of the time (1-10%)	47	26.4
Almost Never	61	34.3
Total Known	178	100.0
Unknown	1	-

Bryk and Schupack (1973) results are based on boaters in general. In cases where accident demographics depart from those for the general boating population, the former should be used, since PFD performance parameters are defined relative to accident situations. In any case, reference sources are needed which (unlike those now available) distinguish between pleasure cruising, sailing, and canoeing/kayaking. Of course, this discrimination can also be partially made on the basis of boat type rather than activity.

The second part of Table III-10 shows the distribution of evaluations by boat type, overall boat length, and location of principal boating activities. The sample in the present study contains a larger proportion of special purpose craft (canoes, sailboats, etc.) than do the ARM and USCG year-end accident data. The present study also over-represents boats over 26 feet in overall length. The sample should be augmented with respondents whose boats are in the 16-20 feet or less than 16 feet category. The present sample should also be augmented with boaters whose principal location of boating activity is rivers and lakes.

The remaining data in Table III-10 show the distributions of boating (not operating) experience and the respondents' reported rate of PFD wear. Most of the boaters in the present study were highly experienced. Boating rather than operating experience was used because it should be more closely related to PFD use and because it applies to all the participants.

Table III-11 summarizes the respondent's attitudes toward PFDs and the use of PFDs. A high percentage of respondents agreed that it is wise to keep PFDs accessible and expressed a tendency to use a PFD in rough or emergency conditions. Very few respondents expressed high confidence in the effectiveness and reliability of PFDs. Only a moderate percentage of the respondents (50.3%) indicated strongly that they felt a need for a PFD when forced into the water in an accident. The results also indicate that using a PFD does not necessarily enhance one's "image" and that many respondents are unenthusiastic about wearing a PFD. It should be noted that the questions in each of these dimensions were selected on the basis of their content and that each item was given equal weight. Psychologically speaking, each scale therefore probably does not represent a unitary attitudinal dimension and, of course, "high," "medium," and "low" have different (and possibly multiple) meanings for each dimension. In future work, it would be desirable to factor

TABLE III-11. DEFINITIONS OF VARIABLES AND PFD-RELATED ATTITUDES OF BOATERS IN THE WEARABILITY/ACCESSIBILITY STUDY

Attitude Dimension	Designation and Method of Computation	Percent of PFD Evaluations on Which the Boater Scored:			
		Low (0 - .333)	Medium (.334 - .666)	High (.667 - 1.0)	Totals
Positive about keeping PFDs accessible	NV9 = 1/10(V30 + V38 - 2)	6.7	20.7	72.6	100.0
Positive about wearing PFD in rough conditions	NV10 = 1/20(V31 + V35 + V41 - V45 + 3)	0.0	5.6	94.4	100.0
Believes PFDs are highly effective and reliable	NV11 = 1/15(V32 - V37 - V42 + 11)	24.3	69.9	5.8	100.0
Believes he/she needs a PFD in the water	NV12 = 1/20(V33 - V44 - V46 + V52 + 10)	6.7	43.0	50.3	100.0
Image (feels positive about wearing a PFD and others who wear PFDs	NV13 = 1/40(V34 - V36 + V39 - V40 + V48 - V49 - V50 - V51 + 27)	11.4	76.0	12.6	100.0
Positive about wearing PFDs	NV14 = 1/10(V47 - V43 + 5)	42.2	37.0	20.8	100.0
Proportion of time candidate PFD was worn	NV1 = V70/V73	Range (0, 1.0)			
Proportion of time candidate PFD was kept accessible or worn	NV5 = (V70 + V71)/V73	Range (0, 1.0)			
Unadjusted Wearability factor score	NV15 = F_W (see equation 12, page III-67)	Range (-4.81, 7.13)			
Unadjusted Accessibility factor score	NV16 = F_A (see equation 11, page III-64)	Range (-6.51, 3.41)			

Variable	Code	Meaning
Kind of PFD tested (NV8)	1	Throwables and devices intended for emergency wear only
	2	Wearable devices which are bulky and unattractive.
	3	Yoke or collar type inflatable devices
	4	Vests and jackets
	5	Belt-type devices
Boating Safety Education (NV6)	0	None
	1	Completed one or more courses
Boating Activities V54 to V64 (see page III-39)	1	Engaged in the activity
	2	Did not engage in the activity
Boat Type (V13)	01	Canoe
	02	Inflatable
	03	Other
	04	Sail
	05	Open Manual
	06	Open Power
	07	Cabin motorboat
	08	Houseboat

analyze responses to these questions and compare boaters with high and low boating experience or boaters with and without boating safety instruction. A study of this sort would help to identify: a) areas where educational efforts related to PFD use should be concentrated, and b) how effectively existing boating safety courses deal with the attitudinal impediments to PFD use.

Table III-12 summarizes the environmental conditions at the time of the PFD evaluations. A fairly large percentage (56.2%) of the evaluations were conducted in choppy or occassionally choppy or rough water conditions. Air temperatures were primarily in the 61-80°F range. Wind was predominately moderate and conditions were mostly sunny.

Appendix III-A,B contains crosstabulations relating the demographic and attitudinal variables discussed above to: a) the proportion of time PFDs were worn in the present study, b) the respondents' reported customary rate of PFD wear (variable 29), c) the proportion of time respondents kept PFDs accessible in the present study, d) the wearability factor scores for candidate PFDs, e) the accessibility factor scores for candidate PFDs, and f) the type of PFD tested classified according to functional and design criteria.

4.3 Derivation of Wearability and Accessibility Factors

PFD wearability and accessibility are defined as average or typical values over the long run, i.e., over the populations of boaters, boating activities, boats, environments, etc. The amount of time that boaters wore PFDs and kept them accessible on individual outings was directly measured in the present study. Wear time for individual outings is a direct measure of wearability. However, it is subject to distortion from the environmental conditions, the type of boat used, and boater's attitudes on the particular outing on which it is measured. That is, wear time is determined by much more than just the properties of the PFD. These non-PFD variables would cancel out if wear time were measured over a sufficiently large random sample of environments, boaters, and boats. Unfortunately, such an approach would be prohibitively costly.

An alternative approach is to measure more basic characteristics of the subject PFD which have known relationships to wearability and accessibility but are less influenced by the conditions prevailing during the boaters' evaluation of a

TABLE III-12. ENVIRONMENTAL CONDITIONS DURING WEARABILITY/ACCESSIBILITY EVALUATIONS OF PFDS

Water Conditions	Percent of PFD Evaluations	Weather Conditions	Percent of PFD Evaluations
Calm	30.3	Sunny	77.3
Choppy or occassionally choppy or rough	56.2	Cloudy	22.7
		Fog/haze	0.0
Rough, swift current, or white water	13.5	Rain	0.0
Total	100.0	Total	100.0

Air Temperature (°F)	Percent of PFD Evaluations	Wind	Percent of PFD Evaluations
40 or less	2.8	Calm	29.5
41 - 50	0.0	Moderate	65.4
51 - 60	2.2	Strong	5.1
61 - 70	43.3	Total	100.0
71 - 80	46.6		
81 - 90	5.1		
Total	100.0		

PFD. The PFD characteristics measured in the present study included seven dimensions in addition to wear and accessibility time:

1. Perceived effectiveness and reliability of the PFD.
2. Perceived appearance of the PFD.
3. Perceived comfort of the PFD.
4. Perceived compatibility of the PFD with the boaters' activities.
5. The boaters' expressed intention as to whether he would wear the PFD if he had it available over the long run.
6. The boaters' expressed intention regarding the accessibility of the PFD over the long run.
7. Image, i.e., how the boater felt about wearing the PFD and how he regarded others who wore it.

The relationships between these characteristics and wear and accessibility time were first established by principal components factor analysis and canonical correlation analysis. Wear and accessibility time were then combined with certain of the above characteristics to obtain the best possible composite estimates of wearability and accessibility.

The results of the factor analysis are shown in Figure III-4. The variables which entered into the factor analysis (V53, NV5, etc.) are shown along the left-hand side of the factor-pattern matrix (Figure III-4). Each variable represents the scores which PFDs received to questions on interview Forms 2 and 3 (see Figure III-3 and Table III-11 for definitions of these variables). Although these variables are related to wearability and accessibility, no single variable or group of variables can be unequivocally called wearability or accessibility. We suspect that wearability/accessibility contributes in some measure to scores on many of the variables. Factor analysis provides a way to estimate the contribution of wearability and accessibility to the scores on each variable. Factor analysis mathematically isolates underlying factors which determine the scores on the variables. It does this by examining the input matrix. The input matrix is simply a listing of scores for each PFD on the variables shown in Figure III-4. The input matrix is illustrated below:

WEARABILITY DATA ANALYSIS 09/19/77 PAGE 14

FILE TED (CREATION DATE = 09/19/77) COLL PFD

QUARTIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION

	FACTOR 1 (WEARABILITY ?)	FACTOR 2 (BODY COVERAGE)	FACTOR 3 (SITUATIONAL)	FACTOR 4 (EFFECTIVENESS)	FACTOR 5 (ACCESSIBILITY)	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	
V53	-.19910	-.71190	-.19894	-.06907	.14620	-.06167	-.21359	.04447	.01801	STYLE (VEST, JACKET, ETC.)
NV5 TIME ACL OR WORN	.09529	.01865	.68613	.08092	.41361	-.06646	-.02662	-.08247	.06614	
NV1 TIME WORN	.35042	.02880	.81782	.05671	-.12075	.14776	-.12803	.00286	-.05078	
V74 ENT ACT TIME WORN	-.39259	-.03094	-.79572	-.06448	.13284	-.12079	.05774	-.02058	-.00850	
V75 RIDE UP	-.79473	.09756	.01421	.15506	-.15143	.02005	.10147	.15289	.09086	
V76 LOOK TENSE, UNCOM.	-.80770	.06428	-.08156	.11683	-.11681	-.01436	-.02902	.30787	.12780	
V77	.23577	.74181	.06811	.08900	.17487	.02277	-.09362	.03529	.16711	KEEP DRY
V78 RESPONSIBLE	.78602	.17352	.09662	.04956	-.01386	-.00489	-.15647	.05494	-.11000	
V79 EASY TO DON	.57668	.13101	.20654	.07723	.01064	-.32519	.07241	.30545	.11484	
V80 LIKE CUT/SHAPE	.80342	.10096	-.08926	.06122	.30096	.06474	.10126	.15732	.04279	
V81 OVERCAUTIOUS	-.45276	.05210	-.04081	.01545	-.04542	-.05785	.09423	.72013	-.04523	
V82 DOESN'T RESTRICT M.	.84930	.05789	.07126	-.11510	.02713	-.07615	.09018	-.04526	-.09301	
V83	.09819	-.20241	-.02410	-.15665	-.13209	-.16895	-.00851	.02816	-.82869	
V84 OILY ROUGH (ON)	-.49738	.05584	-.14650	.19265	.06742	.09024	.53121	.25963	.03537	
V85 GENUINE EMERG.	.34765	.39848	.03520	.68597	-.00405	.02816	-.00163	.07891	.06094	
V86 CUSHION/PILLOW	-.06380	.31596	-.12941	-.23531	.62638	.03592	-.07210	.02903	.02861	
V87	.21899	.80803	-.09201	.04663	.10329	.02183	-.05573	.01471	.17768	WARM
V88 ADVENTUROUS	-.53220	-.16409	-.09652	-.21838	.05953	.23907	.14082	.36786	-.05694	
V89 LOOK AWK, UNATTR.	.86264	-.08543	-.06454	-.01394	.01098	-.02397	-.07796	.22787	-.00829	
V90	.02628	.16191	.15890	-.11064	-.00459	.75316	.02136	-.02341	.10597	COLOR MATCH
V91 FITS SNUGLY	.67643	.22163	.01812	.06410	-.09154	-.16639	.09772	.25599	.15778	
V92 FLAT/COMPACT	.69155	-.20255	-.15056	.10817	.21039	.17796	.19991	-.02610	-.17361	
V93	-.01714	.16999	.11887	.80419	.02569	-.05774	-.10330	-.01503	.03309	EFFECTIVE
V94 NOT HOT	.34170	-.72349	.14254	-.01615	-.03224	-.04911	.08144	-.08790	.10290	NOT HOT/SWEATY
V95 DOES NOT RUB	.67840	-.05084	-.06706	-.11735	.04352	-.28359	-.00090	.12229	.32919	
V96 DOESN'T DETRACT	.85633	-.01383	.01870	-.14255	.05490	.02688	.06767	.01419	.06887	
V97 EXPERT WILL WEAR	-.51960	.01921	-.15626	-.16571	.06594	-.10861	.58344	.08867	-.05963	
V98 COMF. WEAR HOURS	.87889	.09234	.04140	-.04409	-.12145	-.04154	.05593	.13403	-.10588	
V99	.22503	.73262	-.00477	.32990	.09135	.05493	.12121	.15149	-.01658	PROT. FROM IMPACT
V100	.08101	-.69711	-.02649	-.34432	.05591	.03350	.01316	.20267	.10669	PREVENT SUNTAN
V101	.18866	.36438	.00418	.74825	.02465	-.13405	.09409	-.02517	.08713	
V102	.23543	.33648	.11543	-.16503	-.09887	.32139	-.06763	-.07263	.18021	
V103 WOULD WEAR	.72943	.02418	-.03845	.29060	-.16292	.19929	-.12467	.07853	.14744	
V104 BULKY	-.74573	.17814	.02539	-.00104	.12277	-.03225	-.13667	.07945	.01004	
V105	.17716	-.04075	.14923	.19231	.78602	-.09833	.14747	-.08573	.06390	WOULD KEEP ACC.
V106 WOULD WEAR	.63736	.06704	.24880	.12567	.05456	.16417	-.51799	.04167	.04575	
V107 LOOK CONFIDENT	.61323	.15909	.03555	.26276	.03987	.15038	-.18689	.06806	-.08638	
V108 COLOR/PATTERN	.40486	.06279	-.02123	-.04832	.43427	.33164	.42656	-.02041	.19957	COLOR/PATTERN ATTRACTIVE
V109 USEFUL	.41864	-.05592	-.11437	.14381	.49582	.46231	-.20972	.23654	-.00486	USEFUL BESIDES FLOTATION
V110 RELAXED, CASUAL	.74312	.04678	.07721	.12446	-.07795	.05666	-.20148	-.13472	-.05977	

FIGURE III-4. FACTOR ANALYSIS OF THE WEARABILITY/ACCESSIBILITY DATA RELATING TO PFD PROPERTIES (FACTOR PATTERN MATRIX)

	VARIABLES							
PFD #	V53	NV5	NV1	V74	V75	V76	V77	.... V110
1	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	....
2	X_{21}							
3	.	Entries are the scores which each PFD received on each variable.						
104	⋮							
143								
162								
163								
164								
⋮								

Factor analysis looks for correlations among the scores of the many variables. Variables which are strongly correlated must be determined by a common factor or factors. Figure III-5 shows the means, standard deviations, and intercorrelations among variables representing the characteristics of PFDs. Factor analysis uses the intercorrelations between variables to identify the underlying factors which account for most of the variability in the scores of the input matrix. The procedure is similar in principal to a physician who has many patients with various symptoms. He looks for correlations among symptoms in order to identify the underlying diseases. We can think of PFDs as patients, the scores on the variables as symptoms, and the underlying factors as the diseases. Like the physician, we are interested in dealing with the underlying factors rather than just the symptoms.

Of course, any given symptom may be present in several diseases. A runny nose may be present in cases of pneumonia, common cold, and hay fever. Furthermore, a given symptom may not invariably appear when the patient has a certain disease. We may wish to know the correlation of each symptom with various diseases for purposes of diagnosis. This is precisely what the factor-pattern matrix in Figure III-7 gives us. The entries represent the correlation of each variable (symptom) with each of several underlying factors (diseases). A high correlation (either positive <u>or</u> negative) means that the variable in question is strongly related to the factor represented by the column of correlations.

WEARABILITY DATA ANALYSIS 09/19/77 PAGE 6

FILE TED (CREATION DATE = 09/19/77) DOLL PFD

VARIABLE	MEAN	STANDARD DEV	CASES *
V53	2.1838	1.3058	185
NV5	.7817	.3732	179
NV1	.3880	.3787	181
V74	3.1444	1.4068	180
V75	3.3867	2.0588	181
V76	3.1657	1.9650	181
V77	2.5246	1.7938	183
V78	3.1923	1.8211	182
V79	4.5193	1.7211	181
V80	3.8278	2.0218	180
V81	3.7459	1.7197	181
V82	3.6796	1.9342	181
V83	3.4278	1.6445	180
V84	3.7444	1.9408	180
V85	3.6044	1.9938	182
V86	2.6703	1.8541	182
V87	2.7432	1.8999	183
V88	3.4645	1.8150	183
V89	3.4615	1.9486	182
V90	2.4916	1.6604	179
V91	4.0112	1.6760	179
V92	3.7814	1.7963	183
V93	3.5165	1.9460	182
V94	3.7989	1.6193	179
V95	4.2473	1.7142	182
V96	3.5389	1.8771	180
V97	4.4754	1.5788	183
V98	3.5956	1.9641	183
V99	3.3934	1.8452	183
V100	3.2198	1.9200	182
V101	4.2637	1.6103	182
V102	1.6358	1.5033	151
V103	2.6906	1.8807	181
V104	3.4804	1.9727	179
V105	4.5464	1.5324	183
V106	2.4066	1.6948	182
V107	2.9056	1.6124	180
V108	4.2514	1.5836	183
V109	3.3533	1.9305	184
V110	2.7104	1.5892	183

ADDITIONAL VARIABLE DEFINITIONS:

NV 1 = Proportion of time the candidate was worn = V 70/V 73.

NV 5 = Proportion of time the candidate PFD was kept accessible or worn = (V 70+V 71)/V 73.

*Cases = The number of PFD evaluations in which the question or questions corresponding to a specified variable were answered.

FIGURE III-5. INTERCORRELATIONS OF PFD PROPERTIES

WEARABILITY DATA ANALYSIS 09/19/77 PAGE 7

FILE TED (CREATION DATE = 09/19/77) COLL PFD

CORRELATION COEFFICIENTS..

	V53	NV5	NV1	V74	V75	V76	V77	V78	V79	V80
V53	1.00000	-.11335	-.21096	.22860	.01033	.09783	-.44742	-.23511	-.22369	-.20442
NV5	-.11335	1.00000	.40253	-.39946	-.08154	-.15277	.19399	.10634	.18875	.12697
NV1	-.21096	.40253	1.00000	-.87644	-.29761	-.35608	.13374	.39077	.26673	.19636
V74	.22860	-.39946	-.87644	1.00000	.31241	.36335	-.15268	-.41959	-.30325	-.23649
V75	.01033	-.08154	-.29761	.31241	1.00000	.77507	-.09148	-.63263	-.30539	-.60135
V76	.09783	-.15277	-.35608	.36335	.77507	1.00000	-.15146	-.60595	-.36518	-.64373
V77	-.44742	.19399	.13374	-.15268	-.09148	-.15146	1.00000	.32235	.23467	.30254
V78	-.23511	.10634	.39077	-.41959	-.63263	-.60595	.32235	1.00000	.47348	.59518
V79	-.22369	.18875	.26673	-.30325	-.30539	-.36518	.23467	.47348	1.00000	.52274
V80	-.20442	.12697	.19636	-.23649	-.60135	-.64373	.30254	.59518	.52274	1.00000
V81	.06440	-.17127	-.17437	.20565	.43715	.54293	-.06491	-.36220	-.10577	-.25024
V82	-.20888	.12643	.32660	-.34379	-.69704	-.69195	.21009	.66721	.52286	.66892
V83	.13083	-.05788	-.02651	.04954	-.13444	-.17659	-.25576	.07803	-.00335	-.04424
V84	.02534	-.12390	-.33295	.29873	.44016	.48975	-.06862	-.40333	-.22480	-.29228
V85	-.40629	.10512	.20194	-.24063	-.15298	-.14376	.40233	.41300	.33968	.36094
V86	-.10496	.05375	-.14886	.13882	-.08680	-.01761	.21317	-.01127	.02176	.11999
V87	-.52610	.06517	.02273	-.04695	-.10271	-.08754	.77170	.25866	.17616	.31224
V88	.23088	-.17405	-.25009	.27076	.34450	.49009	-.17651	-.44590	-.41174	-.36245
V89	.28473	-.09893	-.38398	.39828	.70584	.74082	-.23971	-.65271	-.44492	-.67562
V90	-.18134	.12135	.18617	-.10977	.03415	-.04930	.17605	.02049	-.05284	.05074
V91	-.33742	.16325	.15973	-.22170	-.40578	-.38753	.33141	.50672	.54793	.52560
V92	.03663	.10904	.11399	-.11829	-.53677	-.58955	.06306	.46586	.25650	.67154
V93	-.16320	.17182	.11276	-.10428	.10952	.09103	.23707	.05631	.14528	.01192
V94	.35977	.13349	.16206	-.18464	-.30414	-.34981	-.34204	.13121	.17471	.14834
V95	-.03962	.05931	.15852	-.17782	-.55431	-.48505	.16879	.46538	.41256	.55527
V96	-.15983	.14306	.25890	-.32516	-.65010	-.70182	.13008	.65692	.48540	.71126
V97	.10647	-.25487	-.37586	.32998	.43384	.39965	-.17779	-.47522	-.25769	-.36822
V98	-.22155	.05016	.33942	-.38293	-.65500	-.64437	.23209	.74090	.54025	.65640
V99	-.56348	.06615	.12373	-.11446	-.02553	-.09167	.60130	.30046	.27845	.34879
V100	.46317	-.04236	-.07691	.05324	-.12301	-.08822	-.47338	-.07996	-.04089	.02215
V101	-.32152	.06792	.11066	-.14122	-.01079	-.07439	.39671	.23043	.23101	.26436
V102	-.18647	.09845	.18137	-.22411	-.16393	-.18464	.31673	.22419	.11199	.16856
V103	-.18770	.01216	.29641	-.37347	-.52124	-.52934	.20889	.60933	.36945	.58739
V104	.07373	.00362	-.25001	.27696	.60323	.59539	-.09230	-.44930	-.36032	-.50073
V105	.02765	.38371	.06869	-.05939	-.22248	-.21281	.19029	.11098	.11383	.32431
V106	-.16957	.20109	.52898	-.49418	-.52663	-.48662	.30085	.62463	.31288	.45923
V107	-.27831	.15146	.27562	-.29793	-.37412	-.39326	.32568	.51542	.32828	.47322
V108	-.19910	.14716	.04907	-.10760	-.30592	-.35082	.18543	.24855	.16586	.50695
V109	.04932	.12701	.10165	-.12258	-.33699	-.29777	.13754	.32545	.20277	.55666
V110	-.18981	.08966	.38607	-.39241	-.60006	-.57852	.23476	.59630	.37228	.46121

NOTE: N1 and NV5 are negatively correlated with V74 because V74 was coded such that the lowest code corresponds to the highest rate of wear (see Figure III-3).

FIGURE III-5. (continued)

FILE TED (CREATION DATE = 09/19/77) DOLL PFD

	V81	V82	V83	V84	V85	V86	V87	V88	V89	V90
V53	.06440	-.20888	.13083	.02534	-.40629	-.10496	-.52610	.23088	.28473	-.18134
NV5	-.17127	.12643	-.05788	-.12390	.10512	.05375	.06517	-.17405	-.09893	.12135
NV1	-.17437	.32660	-.02651	-.33295	.20194	-.14886	.02273	-.25009	-.38398	.18617
V74	.20565	-.34379	.04954	.29873	-.24063	.13882	-.04695	.27076	.39828	-.10977
V75	.43715	-.69704	-.13444	.44016	-.15298	-.08680	-.10271	.34450	.70584	.03415
V76	.54293	-.69195	-.17659	.48975	-.14376	-.01761	-.08754	.49009	.74082	-.04930
V77	-.06491	.21009	-.25576	-.06862	.40233	.21317	.77170	-.17651	-.23971	.17605
V78	-.36220	.66721	.07803	-.40333	.41300	-.01127	.25866	-.44590	-.65271	.02049
V79	-.10577	.52286	-.00335	-.22480	.33968	.02176	.17616	-.41174	-.44492	-.05284
V80	-.25024	.66892	-.04424	-.29228	.36094	.11999	.31224	-.36245	-.67562	.05074
V81	1.00000	-.41288	-.02720	.42573	-.08641	.04993	-.06954	.40202	.47460	-.09377
V82	-.41288	1.00000	.13815	-.41143	.27104	-.01875	.21786	-.43638	-.78003	.01404
V83	-.02720	.13815	1.00000	-.16365	-.19687	-.18415	-.25897	.03490	-.01529	-.15574
V84	.42573	-.41143	-.16365	1.00000	-.02010	.09663	-.05025	.41859	.41841	-.03635
V85	-.08641	.27104	-.19687	-.02010	1.00000	.00779	.42671	-.36487	-.34172	.01990
V86	.04993	-.01875	-.18415	.09663	.00779	1.00000	.20003	.07442	.01166	.09067
V87	-.06954	.21786	-.25897	-.05025	.42671	.20003	1.00000	-.16121	-.23455	.12077
V88	.40202	-.43638	.03490	.41859	-.36487	.07442	-.16121	1.00000	.55318	.05080
V89	.47460	-.78003	-.01529	.41841	-.34172	.01166	-.23455	.55318	1.00000	-.06137
V90	-.09377	.01404	-.15574	-.03635	.01990	.09067	.12077	.05080	-.06137	1.00000
V91	-.18606	.51124	-.02219	-.23879	.37573	-.05899	.29143	-.33385	-.49116	.01931
V92	-.31196	.56301	.13157	-.22809	.19174	-.03949	.01083	-.28047	-.56847	.06320
V93	-.02073	-.04999	-.10035	.04440	.56927	-.09988	.20201	-.18892	.00808	.02139
V94	-.22452	.26899	.14504	-.23744	-.16903	-.19422	-.45631	-.05516	-.26253	-.10026
V95	-.23282	.54183	-.02874	-.32218	.14511	-.03104	.19522	-.31742	-.54380	-.09285
V96	-.39435	.70386	.04123	-.44521	.16381	-.02976	.13216	-.43702	-.69076	.06678
V97	.34125	-.38447	.00943	.50427	-.28808	.08412	-.12393	.37122	.46645	-.09133
V98	-.29184	.79162	.17436	-.38156	.31185	-.08080	.22675	-.46800	-.71787	.03171
V99	.05153	.20724	-.21073	.05425	.58927	.15657	.63711	-.26323	-.22809	.15274
V100	.00031	.08433	.18059	-.10043	-.42806	-.16730	-.47102	.20293	.05980	-.01693
V101	-.06338	.09013	-.18880	.07215	.66457	-.05102	.37499	-.31756	-.19258	-.10494
V102	-.14729	.22130	-.08915	-.13114	.16493	.06769	.31621	-.17469	-.22146	.22967
V103	-.24409	.50681	-.11229	-.29576	.52316	-.06600	.19832	-.41241	-.62594	.08375
V104	.33427	-.63220	-.12382	.31483	-.15178	.12885	-.05297	.30529	.67716	-.03639
V105	-.11782	.18440	-.14881	.02909	.17146	.29511	.09147	-.11579	-.20233	-.05399
V106	-.34624	.48257	-.04543	-.55345	.32664	-.06535	.22490	-.38576	-.52080	.16619
V107	-.26887	.44455	-.00876	-.26664	.38218	-.04042	.28885	-.31785	-.52186	.00066
V108	-.19401	.30384	-.18929	-.00181	.14344	.20298	.21333	-.03320	-.36227	.20275
V109	-.13364	.28916	-.10448	-.15156	.23687	.24714	.13204	-.15374	-.28669	.27993
V110	-.41573	.55880	.06732	-.44212	.30695	-.10878	.20453	-.48459	-.66661	.02787

FIGURE III-5. (continued)

FILE TED (CREATION DATE = 09/19/77) DOLL PFD

	V91	V92	V93	V94	V95	V96	V97	V98	V99	V100
V53	-.33742	.03663	-.16320	.35977	-.03962	-.15983	.10647	-.22155	-.56348	.46317
NV5	.16325	.10904	.17182	.13349	.05931	.14306	-.25487	.05016	.06615	-.04236
NV1	.15973	.11399	.11276	.16206	.15852	.25890	-.37586	.33942	.12373	-.07641
V74	-.22170	-.11829	-.10428	-.18464	-.17782	-.32516	.32998	-.38293	-.11446	.05324
V75	-.40578	-.53677	.10952	-.30414	-.55431	-.65010	.43384	-.65500	-.02553	-.12301
V76	-.38753	-.58955	.09103	-.34981	-.48505	-.70182	.39965	-.64437	-.09167	-.08822
V77	.33141	.06306	.23707	-.34204	.16879	.13008	-.17779	.23209	.60130	-.47338
V78	.50672	.46986	.05831	.13121	.46938	.65692	-.47522	.74090	.30046	-.07996
V79	.54793	.25650	.14528	.17471	.41256	.48540	-.25769	.54025	.27845	-.04089
V80	.52560	.67154	.01192	.14834	.55527	.71126	-.36822	.65640	.34879	.02215
V81	-.18606	-.31196	-.02073	-.22452	-.23282	-.39435	.34125	-.29184	.05153	.00031
V82	.51124	.56301	-.04999	.26899	.54183	.70386	-.38447	.79162	.20724	.08433
V83	-.02219	.13157	-.10035	.14504	-.02874	.04123	.00943	.17436	.21073	.18059
V84	-.23879	-.22809	.04440	-.23744	-.32218	-.44521	.50427	-.38156	.05425	-.10043
V85	.37573	.19174	.56927	-.16903	.14511	.16381	-.28808	.31185	.98927	-.42806
V86	-.05899	-.03949	-.09988	-.19422	-.03104	-.02976	.08412	-.08080	.15657	-.16730
V87	.29143	.01083	.20201	-.45631	.19522	.13216	-.12393	.22675	.63711	-.47102
V88	-.33385	-.28047	-.18892	-.05516	-.31742	-.43702	.37122	-.46800	-.26323	.20293
V89	-.49116	-.56847	.00808	-.26253	-.54380	-.69076	.46645	-.71787	-.22809	.05980
V90	.01931	.06320	.02139	-.10026	-.09285	.06678	-.09133	.03171	.15274	-.01693
V91	1.00000	.42884	.10784	.02849	.52349	.60036	-.27148	.65623	.31733	-.04278
V92	.42884	1.00000	-.02576	.32862	.36546	.57101	-.24990	.56194	.08742	.12069
V93	.10784	-.02576	1.00000	-.10446	-.01554	-.09959	-.16703	-.02365	.35045	-.35752
V94	.02849	.32862	-.10446	1.00000	.27677	.26126	-.19829	.22506	-.44365	.46458
V95	.52349	.36546	-.01554	.27677	1.00000	.60223	-.27150	.55343	.11848	.15980
V96	.60036	.57101	-.09959	.26126	.60223	1.00000	-.38485	.75725	.16579	.12823
V97	-.27148	-.24990	-.16703	-.19829	-.27150	-.38485	1.00000	-.38597	-.08719	.02745
V98	.65623	.56194	-.02365	.22506	.55343	.75725	-.38597	1.00000	.23972	.03875
V99	.31733	.08742	.35045	-.44365	.11848	.16579	-.08719	.23972	1.00000	-.53790
V100	-.04278	.12069	-.35752	.46458	.15980	.12823	.02745	.03875	-.53790	1.00000
V101	.27543	.08408	.63319	-.20937	.10552	.09579	-.12759	.18732	.62512	-.42615
V102	.19772	.10106	.01330	-.12429	.06178	.26678	-.17841	.24417	.14269	-.08870
V103	.52299	.49438	.14687	.21539	.40374	.52297	-.53691	.63351	.22534	-.07170
V104	-.44962	-.53435	.04457	-.45123	-.49284	-.57436	.36890	-.59831	-.04409	-.11352
V105	.10674	.28325	.13821	.04931	.13149	.15687	.00737	.07153	.10990	.06228
V106	.42250	.30756	.17087	.11577	.40179	.49147	-.61671	.52986	.17740	-.02199
V107	.46070	.38285	.14925	.08896	.24761	.51450	-.49114	.51163	.29950	-.12326
V108	.22632	.35357	-.08382	.11236	.28000	.45316	-.00630	.28547	.21981	.06504
V109	.16485	.43925	.08650	.08152	.23055	.38792	-.26470	.28337	.21432	.08369
V110	.47108	.42232	.07389	.22466	.42123	.58060	-.49449	.62944	.17398	-.07468

FIGURE III-5. (continued)

FILE TED (CREATION DATE = 09/19/77) DOLL PFD

	V101	V102	V103	V104	V105	V106	V107	V108	V109	V110
V53	-.32152	-.18647	-.18770	.07373	.02765	-.16957	-.27831	-.19510	.04932	-.18981
NV5	.06792	.09845	.01216	.00362	.38371	.20109	.15146	.14716	.12701	.08966
NV1	.11066	.18137	.29641	-.25001	.06869	.52898	.27562	.04907	.10165	.38607
V74	-.14122	-.22411	-.37347	.27696	-.05939	-.49418	-.29793	-.10760	-.12258	-.39241
V75	-.01079	-.16393	-.52124	.60323	-.22248	-.52663	-.37412	-.30592	-.33699	-.60006
V76	-.07439	-.18464	-.52934	.59539	-.21281	-.48662	-.39326	-.35082	-.29777	-.57852
V77	.39671	.31673	.20889	-.09230	.19029	.30085	.32568	.18543	.13754	.23476
V78	.23043	.22419	.60933	-.44930	.11098	.62463	.51542	.24855	.32545	.59630
V79	.23101	.11199	.36945	-.36032	.11383	.31288	.32828	.16586	.20277	.37228
V80	.26436	.16856	.58739	-.50073	.32431	.45923	.47322	.50695	.55666	.46121
V81	-.06338	-.14729	-.24409	.33427	-.11782	-.34624	-.26887	-.19401	-.13364	-.41573
V82	.09013	.22130	.50681	-.63220	.18440	.48257	.44455	.30384	.28916	.55880
V83	-.18880	-.08915	-.11229	-.12382	-.14881	-.04543	-.00876	-.18529	-.10448	.06732
V84	.07215	-.13114	-.29576	.31483	.02909	-.55345	-.26664	-.00181	-.15156	-.44212
V85	.66457	.16493	.52316	-.15178	.17146	.32664	.38218	.14344	.23687	.30695
V86	-.05102	.06769	-.06600	.12885	.29511	-.06535	-.04042	.20298	.24734	-.10878
V87	.37499	.31621	.19832	-.05297	.09147	.22490	.28885	.21333	.13204	.20453
V88	-.31756	-.17469	-.41241	.30929	-.11979	-.38976	-.31785	-.03320	-.15374	-.48459
V89	-.19258	-.22146	-.62594	.67716	-.20233	-.52080	-.52186	-.36227	-.28669	-.66661
V90	-.10494	.22967	.08375	-.03639	-.05399	.16619	.00066	.20275	.27993	.02787
V91	.27543	.19772	.52299	-.44962	.10674	.42250	.46070	.22632	.16485	.47108
V92	.08408	.10106	.49438	-.53435	.28325	.30756	.38285	.35357	.43925	.42232
V93	.63319	.01330	.14687	.04457	.13821	.17087	.14925	-.08382	.08650	.07389
V94	-.20937	-.12429	.21539	-.45123	.04931	.11577	.08896	.11236	.08152	.22466
V95	.10552	.06178	.40374	-.49284	.13149	.40179	.24761	.28000	.23055	.42123
V96	.09579	.26678	.52297	-.57436	.15687	.49147	.51450	.45316	.38792	.58060
V97	-.12759	-.17841	-.53691	.36890	.00737	-.61671	-.49114	-.00630	-.26470	-.49449
V98	.18732	.24417	.63351	-.59831	.07153	.52986	.51163	.28547	.28337	.62944
V99	.52512	.14269	.22534	-.04409	.10990	.17748	.29950	.21581	.21432	.17398
V100	-.42615	-.08870	-.07170	-.11352	.06228	-.02199	-.12326	.06504	.08369	-.07468
V101	1.00000	.08342	.30826	-.04062	.20927	.17899	.31627	.10292	.07982	.19589
V102	.08342	1.00000	.24894	-.05013	-.02326	.19504	.18952	.14532	.13431	.16320
V103	.30826	.24894	1.00000	-.50977	.03825	.56879	.49976	.23524	.33907	.58615
V104	-.04062	-.05013	-.50977	1.00000	-.09886	-.39536	-.43807	-.25212	-.21785	-.54787
V105	.20927	-.02326	.03825	-.09886	1.00000	.19441	.16064	.40830	.29086	.12585
V106	.17899	.19504	.56879	-.39536	.19441	1.00000	.55619	.15755	.44444	.61676
V107	.31627	.18952	.49976	-.43807	.16064	.55619	1.00000	.27842	.36838	.63950
V108	.10292	.14532	.23524	-.25212	.40830	.15755	.27842	1.00000	.40971	.24304
V109	.07982	.13431	.33907	-.21785	.29086	.44444	.36838	.40971	1.00000	.30333
V110	.19589	.16320	.58615	-.54787	.12585	.61676	.63950	.24304	.30333	1.00000

FIGURE III-5. (concluded)

The factor analysis does not name the factors for us. However, the factors can be named (identified) in terms of the variables they affect, just as a disease can be named for its symptoms. The factor analysis was performed in order to identify one factor which could be unequivocally identified as wearability. We would expect the wearability factor to have high loadings (correlations) on variables which represent actual wear time (NV1 and V74) and at least some variables which represent those PFD properties which lead to high wear rates (e.g., comfort, appearance, etc.). The first factor in Figure III-4 comes closest to satisfying these criteria. However, it falls short in that the variables which represent actual wear time (NV1 and V74) have only moderate correlations (0.35 and -0.39). These moderate correlations may be indicative of either of two underlying situations: 1) the first factor is not wearability but rather something closely related, such as general acceptability; 2) the first factor is wearability but actual wear time is also related to situational variables (environment, boat type, wearers' attitudes) and these relationships attenuate the relationship of wear time with wearability.

In order to insure that the final factor used in the present study was indeed wearability, canonical correlation analyses were performed. Canonical correlation is the multivariate parallel to multiple regression. In multiple regression, one dependent variable is related via a regression formula to multiple independent variables. In canonical correlation, several dependent variables are combined and related simultaneiously to multiple independent variables. Canonical correlation defines two types of canonical variates or factors: one for the independent variable set and another for dependent variables. Each canonical variate is a linear combination of variables, e.g.,

$$\text{canvar}_1 = cv_{11}\, y_1 + cv_{12}\, y_2 + \cdots$$
$$\text{canvar}_2 = cv_{21}\, x_1 + cv_{22}\, x_2 + \cdots$$

where

canvar_1 = a canonical variate which combines the dependent variables, y_1, y_2, etc.

$canvar_2$ = a canonical variate which combines independent variables, x_1, x_2, etc.

$Canvar_1$ and $canvar_2$ are called a "set" of canonical variates. They are defined in such a way that they account for as much of the relationship between the dependent and independent variables as possible. In most cases, the relationship between dependent and independent variables is complex and cannot be entirely explained by one set of canonical variates. Additional pairs of canonical variates are therefore defined to account for whatever part of the relationship is not accounted for by the first set.

Two types of canonical correlation analyses were performed in the present project. In one case, the dependent variables were actual wear time (NV1 and V74). In the second case, the dependent variables were the boaters' intention to wear the PFDs (V103 and V106). As mentioned earlier, each of these types of dependent variables has certain advantages. Actual wear time is a more direct measure of wearability, but it is subject to fluctuations due to the particular environment, boater, and equipment in use when it is measured. Intention to wear is subject to systematic errors (e.g., boaters probably over-estimate how much they would wear a PFD), but is probably less subject to error from environmental conditions, boater's attitudes, and equipment. The intentional variables are therefore likely to be more stable, but inflated, measures of wearability. The canonical correlation analyses for wearability are shown in Figures III-6 and III-7.

Figure III-6 presents the canonical correlation analysis for wearability in which the dependent variables were actual wear time. Looking at the first canonical variate for the second (independent) set of variables, three variables have relatively high coefficients: V76, V89, and V106. The last of these has by far the highest coefficient and represents intention to wear the PFD. This result shows that actual wear time is strongly related to intention to wear. The other variables with high coefficients (V76 and V89) represent the image dimension (i.e., how the boater felt about wearing the PFD and how he would regard others who wear it). The image variables were also strong determinants of intention to wear (see Figure III-7). In the second canonical analysis (Figure III-7), V78, V97, and V110 are among the variables in the independent

FILE TED (CREATION DATE = 10/18/77) DOLL PFD

- - - - - - - - - - - - - - - - - - C A N O N I C A L   C O R R E L A T I O N - - - - - - - - - - - - - - - - - -

NUMBER	EIGENVALUE	CANONICAL CORRELATION	WILK S LAMBDA	CHI-SQUARE	D.F.	SIGNIFICANCE
1	$\boxed{.41768}$	.64628	.49198	112.78175	50	.000
2	.15514	.39388	.84486	26.80451	24	.314

COEFFICIENTS FOR CANONICAL VARIABLES OF THE SECOND SET

	CANVAR 1	CANVAR 2
V75	.20233	.21790
~~V76~~	-.39665	-.39779
V78	.08042	-.14290
V79	.21883	-.00790
~~V80~~	-.22445	-.15376
V81	.19145	.39771
V82	-.03899	.07606
~~V84~~	.02446	-.07108
V85	.17389	-.03002
V88	.14914	.14705
~~V89~~	-.42524	-.24920
V91	-.20636	-.18311
V92	-.11449	.66534
~~V94~~	.15928	-.29143
V95	-.20815	.27506
V96	.02440	-.61960
~~V97~~	-.09643	-.55647
V98	.18036	-.01851
V103	-.18300	-.89816
~~V104~~	.06241	.07889
V106	$\boxed{.84121}$	.34971
V107	-.15022	-.11167
~~V108~~	.02964	-.06150
V109	-.18530	-.11552
V110	.11445	.19043

COEFFICIENTS FOR CANONICAL VARIABLES OF THE FIRST SET

	CANVAR 1	CANVAR 2
NV1	$\boxed{.84344}$	1.89784
~~V74~~	-.17459	2.06948

FIGURE III-6. CANONICAL CORRELATION ANALYSIS USING PROPORTION OF TIME THE CANDIDATE PFD WAS WORN AS THE DEPENDENT VARIABLE

FILE TED (CREATION DATE = 10/18/77) DOLL PFD

- - - - - - - - - - - - - - - - - C A N O N I C A L C O R R E L A T I O N - - - - - - - - - - - - - - - - -

NUMBER	EIGENVALUE	CANONICAL CORRELATION	WILK S LAMBDA	CHI-SQUARE	D.F.	SIGNIFICANCE
1	.76592	.87517	.15416	299.16100	46	0
2	.34141	.58430	.65859	66.82471	22	.000

COEFFICIENTS FOR CANONICAL VARIABLES OF THE SECOND SET

	CANVAR 1	CANVAR 2
V75	.00239	-.09448
V76	-.12541	.08601
V78	.21806	.26862
V79	-.12651	.10540
V80	.07056	-.39482
V81	.05587	-.15726
V82	-.14809	.41914
V84	-.13159	-.55045
V85	.19713	-.49082
V88	.02613	.03384
V89	-.09122	.30545
V91	.18529	-.02258
V92	-.08141	-.30910
V94	.06165	-.30490
V95	.02844	.22892
V96	-.13613	-.20042
V97	-.27446	.04221
V98	.18868	-.37260
V104	-.04546	.09989
V107	.03506	.36835
V108	-.03344	.00633
V109	.20499	.46354
V110	.17238	.01704

COEFFICIENTS FOR CANONICAL VARIABLES OF THE FIRST SET

	CANVAR 1	CANVAR 2
V103	.56003	-1.07918
V106	.56906	1.07444

FIGURE III-7. CANONICAL CORRELATION ANALYSIS USING INTENTION TO WEAR AS THE DEPENDENT VARIABLE

set with the highest coefficients; all three of these variables represent the image dimension. These results suggest that actual wear time and intention to wear are strongly related and might be usefully combined to obtain the most reliable and valid measure of wearability.

The following paragraphs outline the use of the canonical variates to develop the wearability factor. The analysis for PFD accessibility was exactly parallel to that for wearability. For brevity, the following discussion will therefore consider only wearability.

The two canonical correlation analyses of wearability data defined four canonical variates of the form:

$$canvar_{jk} = \sum_{i=1}^{N_{jk}} CV_{ijk} Z_{ijk}$$

where

Z_{ijk} = the standardized score which a PFD obtains on the ith variable. This variable enters into the jth canonical variate (j = 1,2) in the k canonical correlation analysis (k = 1,2) for wearability.

CV_{ijk} = the canonical coefficient for variable Z_{ijk}.

$canvar_{jk}$ = the canonical variate, which is a linear combination of variables in the jth set of the kth canonical analysis.

N_{jk} = the number of variables in the jth set of the kth canonical analysis.

The following conventions will be observed:

j = 1 represents the set of dependent variables in each canonical analysis; j = 2 represents the independent set.

k = 1 represents the canonical analysis in which the dependent variables are direct measures of wear time; k = 2 represents the analysis in which dependent variables are the boaters' intention regarding the wear of the PFD.

Variables with low coefficients relative to other variables in the same list were omitted from the canonical variates. The canonical analyses of wearability data produced the following canonical variates (see Figures III-6 and III-7):

1) $canvar_{11} = 0.84\ (NV1)$

2) $canvar_{21} = -0.39\ (V76) -0.43\ (V89) +0.84\ (V106)$

3) $canvar_{12} = 0.56\ (V103) +0.57\ (V106)$

4) $canvar_{22} = 0.22\ (V78) +0.20\ (V85) +0.19\ (V91)$
$-0.27\ (V97 +0.19\ (V98)$
$+0.20\ (V109) +0.17\ (V110)$

where all the above variables (NV1, V76, etc.) have been standardized.

We also know that:

5) $canvar_{11} = b_{(1\cdot 2)1}\ canvar_{21} + a_{(1\cdot 2)1}$

6) $canvar_{12} = b_{(1\cdot 2)2}\ canvar_{22} + a_{(1\cdot 2)2}$

where the $b_{(1\cdot 2)}$s are regression coefficients for predicting the first canonical variate in each set ($canvar_{11}$ or $canvar_{12}$) from the second canonical variate ($canvar_{21}$ or $canvar_{22}$). The $a_{(1\cdot 2)}$s are the intercepts of the regression lines.

Since the canonical variates are standardized:

$b_{(1\cdot 2)1} = r_{(1\cdot 2)1} = 0.65$, the correlation between $canvar_{11}$ and $canvar_{12}$

$a_{(1\ 2)1} = 0$

Similarly,

$b_{(1\cdot 2)2} = r_{(1\cdot 2)2} = 0.88$

$a_{(1\cdot 2)2} = 0$

Substituting the above values in equations 1, 2, and 5, we find that:

$0.84\ (NVI) = 0.65\ [-0.39\ (V76) -0.43\ (V89) +0.84\ (V106)]$

Simplifying, we have a prediction equation for NV1 (proportion of time worn):

7) predicted proportion of time worn = NV1' = -0.30 (V76) -0.33 (V89) +0.65 (V106)

All of the terms on the right-hand side of equation 7 are perceived PFD properties except +0.65 (V106). This last term represents the boater's reported intention to wear (or not wear) the candidate PFD. It is desired to obtain a prediction of proportion of time worn (NV1') that involves only perceived PFD properties and not intention to wear. Such a prediction can be developed as follows.

We can rewrite equation 5 as:

8) predicted proportion of time worn = NV1' = -0.30 (V76) -0.33 (V89) + [intention to wear]

The second canonical correlation analysis for wearability provides a prediction of intention to wear in terms of perceived PFD properties. Using equations 3, 4, and 6 and the above values we obtain after simplifying:

9) predicted intention to wear = 0.64 (V103') +0.65 (V106') = 0.22 (V78) +0.20 (V85) +0.19 (V91) -0.27 (V97) +0.19 (V98) +0.20 (V109) +0.17 (V110)

Substituting equation 9 into equation 8 and simplifying:

10) NV1' = -0.30 (V76) -0.33 (V89) +0.22 (V78) +0.20 (V85) +0.19 (V91) -0.27 (V97) +0.19 (V98) +0.20 (V109) +0.17 (V110)

In order to get the best possible prediction, the wearability factor was defined as the sum of:

a. predicted proportion of time worn (NV1')
b. measured proportion of time worn (NV1)
c. measured intention to wear [0.64 (V103) +0.65 (V106)]

The coefficients 0.64 and 0.65 are used in measured and predicted intention to wear in order to maintain the relative weighting of variables expressed in equation 7.

AD-A058 738 WYLE LABS HUNTSVILLE ALA F/G 6/7

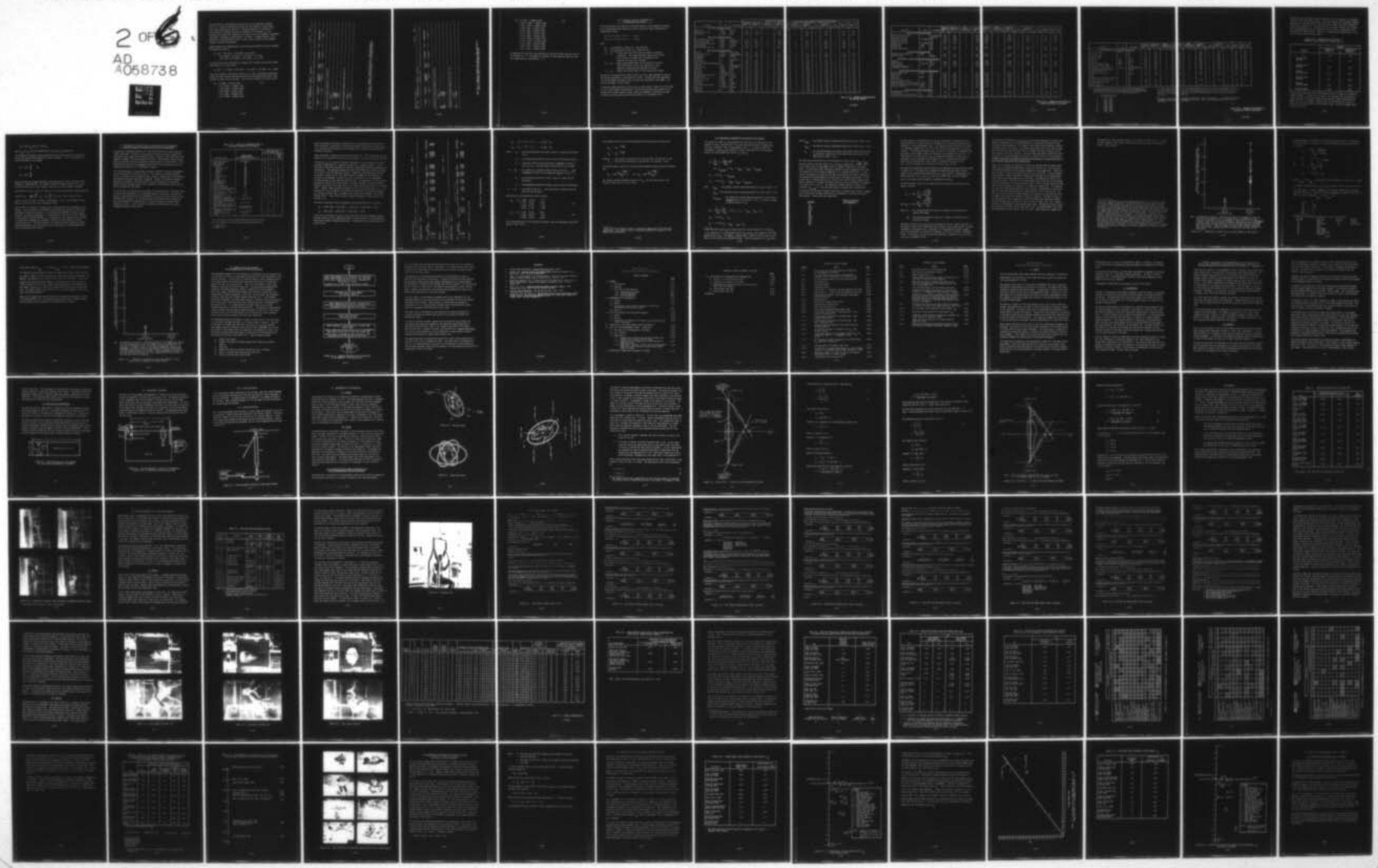
PERSONAL FLOTATION DEVICES RESEARCH. VOLUME 2. RESEARCH REPORT.(U)

JAN 78 T DOLL, M PFAUTH, J GLEASON, S COHEN DOT-CG-42333-A

UNCLASSIFIED MSR-78-1-VOL-2 USCG-D-41-78-VOL-2 NL

2 OF 6

AD
A058738



OF 6

8738

This definition of the wearability factor (F_W) has two important features. First, it is based on perceived PFD properties and intention to wear rather than simply proportion of time worn. Although proportion of time worn is a direct measure of wearability than PFD properties or intentions, it also fluctuates much more with situational variables, such as environmental conditions, the boaters' equipment, and the boaters' attitudes. A second feature of this definition of the wearability factor is that it uses as many of the variables related to PFD wear as possible.

Summing equation 10, measured wear time and measured intention to wear, we obtain the wearability factor:

$$
\begin{aligned}
F_W = {} & NV1 - 0.30\ (V76) - 0.33\ (V89) + 0.65\ (V106) \\
& + 0.64\ (V103) + 0.22\ (V78) + 0.20\ (V85) + 0.19\ (V91) \\
& - 0.27\ (V97) + 0.19\ (V98) + 0.20\ (V109) + 0.17\ (V110)
\end{aligned}
$$

A similar analysis for accessibility produced the following accessibility factor (see Figures III-8 and III-9):

$$F_A = NV5 + 1.0\ (V105) + 0.58\ (V108) + 0.44\ (V86) + 0.27\ (V80) + 0.11\ (V109)$$

Since the variables in the above equations for F_W and F_A represent standardized scores, one must subtract the mean and divide by the standard deviation of each variable in order to use raw scores. The raw score formulas for F_W and F_A are:

$$
\begin{aligned}
F_A = {} & 1.0 *(NV5 - 0.7817)/0.3732 \qquad (11) \\
& + 0.10 *(V105 - 4.5464)/1.5324 \\
& + 0.58 *(V108 - 4.2514)/1.5836 \\
& + 0.44 *(V86 - 2.6703)/1.8541 \\
& + 0.27 *(V80 - 3.8278)/2.0218 \\
& + 0.11 *(V109 - 3.3533)/1.9305
\end{aligned}
$$

WEARABILITY DATA ANALYSIS 10/18/77 PAGE 6

FILE TED (CREATION DATE = 10/18/77) COLL PFD

- - - - - - - - - - - - - - - - - C A N O N I C A L   C O R R E L A T I O N - - - - - - - - - - - - - - - -

NUMBER	EIGENVALUE	CANONICAL CORRELATION	WILK S LAMBDA	CHI-SQUARE	D.F.	SIGNIFICANCE
1	.15212	.39003	.84788	27.97032	5	.000

COEFFICIENTS FOR CANONICAL VARIABLES OF THE SECOND SET

	CANVAR 1
V80	-.02396
V86	-.18062
V105	1.03057
V108	-.03487
V109	.09816

COEFFICIENTS FOR CANONICAL VARIABLES OF THE FIRST SET

	CANVAR 1
NV5	1.00000

FIGURE III-8. CANONICAL CORRELATION ANALYSIS USING PROPORTION OF TIME THE CANDIDATE PFD WAS KEPT ACCESSIBLE AS THE DEPENDENT VARIABLE

FILE TED (CREATION DATE = 10/18/77) DOLL PFD

- - - - - - - - - - - - - - - - C A N O N I C A L C O R R E L A T I O N - - - - - - - - - - - - - - - -

NUMBER	EIGENVALUE	CANONICAL CORRELATION	WILK S LAMBDA	CHI-SQUARE	D.F.	SIGNIFICANCE
1	.23288	.48258	.76712	45.06957	4	.000

COEFFICIENTS FOR CANONICAL VARIABLES OF THE SECOND SET

	CANVAR 1
V80	.26514
V86	.43501
V108	.57797
V109	.11082

COEFFICIENTS FOR CANONICAL VARIABLES OF THE FIRST SET

	CANVAR 1
V105	1.00000

FIGURE III-9. CANONICAL CORRELATION ANALYSIS USING INTENTION TO KEEP THE PFD ACCESSIBLE AS THE DEPENDENT VARIABLE

$$
\begin{aligned}
F_W = {} & 1.0 *(NVI - 0.3880)/0.3784 \\
& + 0.65 * (V106 - 2.4066)/1.6948 \\
& + 0.64 * (V103 - 2.6906)/1.8807 \\
& + 0.22 * (V78 - 3.1923)/1.8211 \\
& + 0.20 * (V85 - 3.6044)/1.9938 \\
& + 0.19 * (V91 - 4.0112)/1.6760 \\
& + 0.19 * (V98 - 3.5956)/1.9641 \\
& + 0.20 * (V109 - 3.3533)/1.9305 \\
& + 0.17 * (V110 - 2.7104)/1.5892 \\
& - 0.33 * (V89 - 3.4615)/1.9486 \\
& - 0.30 * (V76 - 3.1657)/1.9650 \\
& - 0.27 * (V97 - 4.4754)/1.5788
\end{aligned}
\tag{12}
$$

In equations (11) and (12), the variables NV1 and NV5 may each take any value in the internal (0, 1). The remaining variables in these equations may each take any integer value in the interval (1, 6)

4.4 Confidence Intervals for Wearability and Accessibility Factors

The factor analysis and canonical correlation analysis of the wearability-accessibility questionnaire data defined two factors which are linear combinations of questionnaire scores:

$$F_W = a_1 x_1 + a_2 x_2 + a_3 x_3 + \ldots + a_n x_n$$

$$F_A = b_1 x_1 + b_2 x_2 + b_3 x_3 + \ldots + b_n x_n$$

where

F_W = the wearability factor for a specified PFD.

F_A = the accessibility factor for a specified PFD.

$x_1,\ldots,x_n$ = ratings which the PFD was given by boaters on each of n questions. Only those questions have at least 10% of their variance in common with the wearability or accessibility factor are included.

$a_1,\ldots,a_n$ = factor score coefficients for the wearability factor. These coefficients reflect the importance of each question in determining the wearability factor.

$b_1,\ldots,b_n$ = factor score coefficients for the accessibility factor.

Wearability and accessibility factor scores (F_W and F_A) were computed for each of the 185 PFD evaluations in the wearability study. The data were then aggregated for each PFD model, and mean F_W and F_A scores were computed for each model. The results are shown in Table III-13.

It should be noted that many of the F_W and F_A scores shown in Table III-13 are based on only a small number of evaluations. Since the evaluations were generally conducted with different boaters, under varying environmental conditions, and types of boats, the raw F_W and F_A scores may be subject to considerable error.

SEE NOTE AT END OF TABLE CONC

Description	Size	Wyle Numbers	Unadjusted Wearability Factor - F_W	Unadjusted Accessibility Factor - F_A	Number of Observations (N) for F_W and F_A	Adjusted Wearability Factor - F_{W_C}
Type I Coast Guard Approved Devices						
Orange Vest[b]	Adult	261,262	-2.34	-2.32	4	-1.52
Rectangular, Red, Foam	>90 lb	295	-4.03	-1.33	1	-4.64
Red Foam Yoke	L Adult	335	-1.89	-2.34	2	-1.50
Type II Coast Guard Approved Devices						
Cotton and Foam Yoke, Orange	Adult	115,116	-0.75	-0.47	3	-1.51
AK-1 (Nylon and Kapok)	Adult	201,204,206	-0.73	-2.19	4	-0.80
Vinyl Covered Foam Yoke, White	Adult	314,316	-2.63	-0.79	4	-1.01
Vest, Red/Orange	Adult	300,329	-1.38	1.20	5	-1.11
Vinyl Covered Foam Yoke, Red	Adult	336	-2.68	0.02	2	-2.34
Type III Coast Guard Approved Devices						
Blue Vest	M,L,XL	196,197,198	2.06	0.23	6	1.77
Vinyl Ski Vest, Yellow	S,M,L,XL	284,285,286,287	-1.69	0.05	7	-1.01
Yellow Vest - Canoe/Kayak	Adult	348,274	2.22	1.85	4	0.84
Orange Vest	S,L	349,305,306	2.29	0.57	4	2.38
Blue Float Coat	L	302	3.06	-0.78	2	2.68
White Vinyl Covered Vest w/Open Back	L	301	-4.67	-1.91	2	-4.21
Denim Vest	S,M,L	082,084,303,304	1.34	0.67	6	0.91
Light Blue Vest	Adult	246,247,249	-0.47	0.71	3	0.80
Blue Vest	Large	102	-2.10	-2.80	2	-1.28
Green Vest	Medium	186	-2.73	-3.72	1	-1.14
Yellow Vest	Ladies Small	327	2.11	-0.46	2	2.60
Rainbow Colored and White Vest	S,L Adult	331,332	0.96	0.51	4	1.28
Camouflage Vest	Adult	137,138	0.69	0.26	4	1.14
Water Ski Vest, White	Adult	298	-2.42	-0.74	2	-2.40
Yellow Vest	L Adult	326	1.65	1.91	2	2.80
Yellow Vest	M Adult	345,005	0.57	0.08	3	0.90
Blue w/Red, Yellow Trim Vest	S Adult	330	4.49	0.61	2	4.35
Khaki Vest	S,L Adult	333,334	4.18	1.41	5	3.64
Green Vest	L	037	5.18	2.33	1	1.86
Orange Vest	-	998	2.55	0.81	4	2.11

SEE NOTE AT END OF TABLE CONCERNING THE ACCURACY OF THESE ESTIMATES							
Number of Observations (N) for F_W and F_A	Adjusted Wearability Factor - F_{W_C}	N for F_{W_C} and I_W	Adjusted Accessibility Factor - F_{A_C}	N for F_{A_C} and I'_{AC}	Wearability Index - I_W	Accessibility[a] Index - I'_{AC}
4	-1.52	2	-0.55	2	0.01	0.35
1	-4.64	1	-1.18	1	0.0	0.28
2	-1.50	2	0.24	1	0.02	0.43
3	-1.51	2	-1.92	2	0.02	0.21
4	-0.80	4	-2.02	4	0.07	0.20
4	-1.01	3	-0.39	3	0.06	0.45
5	-1.11	3	1.63	4	0.05	0.57
2	-2.34	2	-0.86	2	0.0	0.32
6	1.77	4	0.10	5	0.29	0.42
7	-1.01	6	-0.37	6	0.06	0.37
4	0.84	1	1.05	1	0.21	0.51
4	2.38	3	0.50	3	0.34	0.46
2	2.68	2	-1.12	2	0.37	0.29
2	-4.21	2	-2.25	2	0.0	0.18
6	0.91	5	1.13	6	0.22	0.52
3	0.80	3	1.30	3	0.21	0.54
2	-1.28	2	-2.50	2	0.03	0.15
1	-1.14	1	-2.53	1	0.05	0.15
2	2.60	2	-0.01	2	0.36	0.41
4	1.28	3	1.19	4	0.25	0.53
4	1.14	4	0.36	4	0.24	0.44
2	-2.40	2	-1.64	2	0.0	0.24
2	2.80	1	1.26	2	0.38	0.54
3	0.90	2	0.10	3	0.22	0.42
2	4.35	2	0.04	2	0.51	0.41
5	3.64	4	0.23	4	0.45	0.43
1	1.86	1	0.94	1	0.30	0.50
4	2.11	3	0.52	3	0.32	0.46

TABLE III-13. WEARABILITY/ACCESSIBILITY FACTORS AND INDICES

Description	Size	Wyle Numbers	Unadjusted Wearability Factor - F_W	Unadjusted Accessibility Factor - F_A	Number Observations (N) for F_W and F_A	Adjusted Wearability Factor - F_W
Type IV Coast Guard Approved Devices						
Red Nylon Kapok Filled Cushion	-	176,177,178,179	-3.56	2.45	6	-3.48
Blue Kapok Filled Cushion	-	182,180,183	-3.58	0.96	5	-2.85
White Plastic Ring Buoy	20" Diameter	293	-4.39	-5.09	2	-3.68
Red Kapok Filled Cushion	-	123	-4.81	2.09	1	-5.78
Orange Plastic Ring Buoy	24" Diameter	294	-4.81	-0.70	1	-
Horseshoe Buoy	Large	292	-	-	0	-
Horseshoe Buoy	Small	291	-3.90	-1.07	2	-2.83
Red Kapok Filled Cushion	-	058	-2.75	0.17	1	-1.47
Type V Coast Guard Approved Devices						
Orange and Black Whitewater Vest	Adult	337	-2.40	-0.17	2	-3.03
Work Vest, Orange	-	322,323	-2.71	-3.95	4	-2.70
Hybrid Devices - Not Coast Guard Approved Except as Noted Below						
Hybrid Vest	-	012	0.83	2.98	1	-1.66
Orange Foam Yoke	>5 yrs old	169,173	-2.53	-2.65	3	-2.30
Hybrid Vest, Red (A version of this device is approved as a Type III)	M	307	3.14	1.06	4	1.90
Inherently Buoyant Devices Which Are Not Coast Guard Approved						
Large Foam Yoke, Yellow	Adult	146	-3.27	1.44	2	-2.73
Large Foam Belt	-	155	-3.84	-1.54	2	-3.03
Orange Vest	Adult	142	-2.67	-0.19	4	-3.12
Yellow Ski Belt	-	296	-1.51	1.24	1	-1.34
Thin, Soft Foam Vest, Yellow	-	328	2.93	-0.22	2	3.79
Canoe/Kayak Orange Vest w/Small Air Cells	L Adult	149	4.40	1.06	4	2.73
Life Jacket Meeting Australian Standards	Adult	278	-1.16	1.73	2	-3.26
Float Coat, Light Blue	Large	139	3.42	0.02	2	5.21
Inflatable Devices Not Coast Guard Approved						
Inflatable Collar in Belt, Red and White	-	195	-1.79	-4.34	2	-0.45
Inflatable Tube in Green and White Belt	40	157	0.92	-1.45	2	1.74

Unadjusted ccessibility actor - F_A	Number Observations (N) for F_W and F_A	Adjusted Wearability Factor - F_{W_C}	N for F_{W_C} and I_W	Adjusted Accessibility Factor - F_{A_C}	N for F_{A_C} and I'_{AC}	Wearability Index - I_W	Accessibility[a] Index - I'_{AC}
2.45	6	-3.48	2	2.11	2	0.0	0.62
0.96	5	-2.85	2	1.45	2	0.0	0.55
-5.09	2	-3.68	1	-0.78	1	0.0	0.33
2.09	1	-5.78	1	0.33	1	0.0	0.44
-0.70	1	-	0	-	0	-	-
-	0	-	0	-	0	-	-
-1.07	2	-2.83	2	1.36	1	0.0	0.54
0.17	1	-1.47	1	-0.04	1	0.02	0.40
-0.17	2	-3.03	2	0.20	2	0.0	0.43
-3.95	4	-2.70	3	-4.50	3	0.0	-
2.98	1	-1.66	1	1.99	1	0.0	0.61
-2.65	3	-2.30	3	-2.98	3	0.0	0.10
1.06	4	1.90	4	0.71	4	0.30	0.48
1.44	2	-2.73	1	1.34	2	0.0	0.54
-1.54	2	-3.03	2	-1.25	2	0.0	0.28
-0.19	4	-3.12	4	-0.30	4	0.0	0.38
1.24	1	-1.34	1	0.92	1	0.03	0.50
-0.22	2	3.79	2	-1.89	1	0.46	0.22
1.06	4	2.73	4	0.75	4	0.37	0.48
1.73	2	-3.26	2	1.34	2	0.0	0.54
0.02	2	5.21	2	0.42	2	0.58	0.45
-4.34	2	-0.45	2	0.22	1	0.10	0.43
-1.45	2	1.74	2	-1.15	2	0.29	0.29

TABLE III-13. WEARABILITY/ACCESSIBILITY FACTORS AND INDICES (continued)

2

Description	Size	Wyle Numbers	Unadjusted Wearability Factor - F_W	Unadjusted Accessibility Factor - F_A	Number Observations (N) for F_W and F_A	Ad Wea Fac
Inflatable Devices Not Coast Guard Approved (concluded)						
Khaki Colored Yoke	Adult	152	3.34	0.17	2	
Yellow Sailor's Yoke	-	277	2.17	-1.58	1	
Khaki Colored Yoke	-	154	1.94	0.45	2	
Scuba Vest, Yellow	-	275	-2.63	0.32	3	
Orange Yoke	Adult	161,162	-3.04	-1.28	3	
Orange Yoke	Adult	166,168	0.04	-0.82	4	
Inflatable Suspenders, Orange	Adult	325	0.26	-3.80	2	
Inflatable Tube in Belt, Orange	-	251,252	-0.61	-1.02	3	
Inflatable Tube in Red and White Belt	S,M,L,XL	130,132,255,193,133	1.75	-0.62	9	
Brown/White Belt w/Camouflage Pouch w/Inflatable Tube	-	253,192	2.96	0.91	2	
Belt-worn Inflatable Balloon	-	342,343	1.71	0.68	2	
Orange Yoke	-	341	-0.14	-1.97	1	
Throwable Ball Containing Inflatable Ring	-	340	-	-	0	
Inflatable Tube in Belt Holder, Blue	-	339	2.08	-1.36	1	
Inflatable Tube in Belt Holder, Blue and White	-	338	3.84	0.22	1	
FAA Type Yoke, Yellow	-	344	-0.43	-0.33	1	

NOTE: The accuracy of the estimated factors and indices in this table depends greatly upon the sample size (N) for the factor or index. Those factors or indices based on a sample size (N) of only one or two may be considerably in error. The 90% confidence intervals for I_W and I'_{AC} are given below for various sample sizes (N):

90% Confidence Intervals

N	$I_W \pm$	$I_{AC} \pm$
1	0.240	0.279
2	0.170	0.197
3	0.139	0.161
4	0.120	0.140
5	0.107	0.126
6	0.097	0.115
10	0.076	0.089
15	0.062	0.073
20	0.053	0.063
25	0.048	0.056

[a] I'_{AC} is the estimated probabil is on board. Since the I_W an sample sizes, I_W in some case exceed I'_{AC}.

[b] Throughout this report "vest" the upper torso and shoulders Type II PFD.

...sted ...bility - F_A	Number Observations (N) for F_W and F_A	Adjusted Wearability Factor - F_{W_C}	N for F_{W_C} and I_W	Adjusted Accessibility Factor - F_{A_C}	N for F_{A_C} and I'_{AC}	Wearability Index - I_W	Accessibility[a] Index - I'_{AC}
.17	2	3.59	2	0.30	1	0.44	0.44
.58	1	3.76	1	-0.38	1	0.47	0.37
.45	2	0.10	1	-0.25	1	0.15	0.38
.32	3	-3.12	2	-0.08	3	0.0	0.40
.28	3	-0.70	2	-0.30	2	0.08	0.38
.82	4	0.60	3	-1.49	3	0.19	0.26
.80	2	1.36	2	-1.96	1	0.26	0.21
.02	3	-1.53	2	-1.30	2	0.01	0.28
.62	9	1.64	6	0.05	6	0.28	0.41
.91	2	0.86	2	0.51	2	0.21	0.46
.68	2	4.44	1	0.29	2	0.51	0.44
.97	1	-1.33	1	-3.59	1	0.03	0.04
-	0	-	0	-	0	-	-
.36	1	0.89	1	-2.98	1	0.22	0.11
.22	1	-	0	-	0	-	-
.33	1	-1.14	1	-	0	0.05	-

[a] I'_{AC} is the estimated probability that the PFD is accessible including worn, given that it is on board. Since the I_W and I'_{AC} figures shown in this table are estimates based on small sample sizes, I_W in some cases exceeds I'_{AC} even though the true value of I_W should never exceed I'_{AC}.

[b] Throughout this report "vest" is used in the usual sense, i.e., a sleeveless garmet covering the upper torso and shoulders. Some U.S. Coast Guard publications use "vest" to mean a Type II PFD.

TABLE III-13. WEARABILITY/ACCESSIBILITY FACTORS AND INDICES (concluded)

The next step in the analysis was to establish limits of accuracy, or confidence intervals, for the F_W and F_A scores. Those data records which represent repeated evaluations of the same model of PFD were used to compute the error variance of the F_W and F_A scores, s_e^2. The square root of the error variance, the standard error of measurement (s_e), is a measure of the variation or inaccuracy in the evaluation of a specified PFD. Table III-14 compares the standard errors for F_W and F_A to the range for each variable.

TABLE III-14. STANDARD ERRORS AND RANGES OF WEARABILITY AND ACCESSIBILITY FACTORS (F_W, F_A)

MEASURE	MEASURE	
	WEARABILITY FACTOR, F_W	ACCESSIBILITY FACTOR, F_A
s_e	1.94	1.92
Maximum Value Possible	7.13	3.41
Greatest Value Observed	5.18	2.98
Minimum Value Possible	-4.81	-6.51
Smallest Value Observed	-4.81	-5.09
Maximum Possible Range	11.94	9.92
Observed Range	9.99	8.07

The F_W and F_A scores for a given PFD represent the sum (or mean) of a number of random variables. According to the central limit theorem, the distribution of F_W and F_A scores for a specified PFD should approach a normal distribution as sample size (N) is increased. Assuming that the distributions of F_W and F_A scores for a particular PFD are approximately normal, the 90% confidence limits for each factor are:

$$F_W \pm 1.645\ s_{e_W} \text{ and } F_A \pm 1.645\ s_{e_A}$$

where s_{e_W} and s_{e_A} are the standard errors for F_W and F_A respectively.

The estimates of wearability and accessibility can be made arbitrarily accurate by having the subject PFD evaluated by a sample of boaters. If N is the sample size, the 90% confidence limits become

$$\bar{F}_W \pm 1.645\ \frac{s_{e_W}}{\sqrt{N}} \qquad \text{and}$$

$$\bar{F}_A \pm 1.645\ \frac{s_{e_A}}{\sqrt{N}}$$

where $\bar{F}_W$ and $\bar{F}_A$ are the mean wearability and accessibility factors from the N evaluations of a specified PFD. For example, the 90% confidence intervals for F_W and F_A for the first Type III vest listed in Table III-13 are calculated as follows:

From Table III-13, $\bar{F}_W = 2.06$, $\bar{F}_A = 0.23$, $N = 6$. We can say with 90% confidence that the interval $\left(\bar{F}_W - 1.645\ \frac{s_{e_W}}{\sqrt{N}},\ \bar{F}_W + 1.645\ \frac{s_{e_W}}{\sqrt{N}}\right)$ or (0.76, 3.36) includes the true value of F_W for this PFD. Similarly, the interval (-1.06, 1.52) includes the true value of F_A for this PFD with a confidence of 90%.

The variation in estimates of F_W and F_A for a specified PFD are attributable to two sources. The first source is differences in the conditions under which the PFD was evaluated on different occasions (i.e., different environmental conditions, boater attitudes, and boat and equipment). A second source of variation is error inherent in the system for evaluating PFDs (i.e., limitations of the interview form, incorrect or inconsistent responses due to boaters' inability or unwillingness to follow instructions, etc.). The next section of this report outlines a method for estimating the magnitude of the first kind of error and removing it from estimated wearability and accessibility factors.

4.5 Adjustment of Factor Scores for Variation Due to Environmental Condition, Boaters' Attitudes and Activities, and Equipment

Of necessity, repeated evaluations of a specified PFD were carried out under different conditions. The PFD was evaluated on different occasions by people with varying attitudes about PFDs and boating safety. Moreover, these individuals were generally engaged in different boating activities, used different types of boats, and went out under various environmental conditions while testing the PFD. All of these factors relate to the situation under which PFDs were evaluated, and will therefore be referred to as "situational variables."

This section analyzes the relationship between situational variables and wearability and accessibility ratings (F_W and F_A). This analysis serves two purposes. First, it provides a way to adjust F_W and F_A scores to remove some of the variation introduced by different evaulation situations. Second, it provides information which will be helpful in selecting boaters for PFD evaluations in the future. Boaters who have extreme values on any situational variable which affects F_W or F_A can be excluded from the sample.

The first step in the analysis was to reduce the situational data collected in each of the 185 PFD evaluations into a manageable number of variables. The possible scores on each variable were also categorized so that each variable could be crosstabulated with F_W and F_A. Chi-square measures of association were computed for each crosstabulation to determine which situational variables are most highly related to F_W and F_A. The situational variables crosstabulated with F_W and F_A included are shown in Table III-15.

TABLE III-15. RESULTS OF CROSSTABULATIONS OF SITUATIONAL VARIABLES WITH F_W AND F_A

SITUATIONAL VARIABLE	ITEM OR VARIABLE NUMBER ON INTERVIEW FORM (SEE APPENDICES IIIA AND IIIB)	SIGNIFICANCE LEVEL[c] FOR TEST OF ASSOCIATION WITH: F_W	F_A	TYPES OF PFDs TESTED[b]
1. Boating safety education	V5 through V10	**	—	—
2. Type of boat used	V13	***	—	—
3. Water conditions	V66	—	—	—
4. Boating activity				
Fishing	V54	**	*	—
Canoeing or kayaking	V55	***	—	—
Skindiving	V56	—[a]	—[a]	—[a]
Scuba diving	V57	—	**	—
Swimming	V58	—	—	—
Camping	V59	—[a]	—[a]	—[a]
Sailing	V60	—	—	—
Water skiing	V61	—	—	—
Pleasure cruising	V62	**	—	—
Racing	V63	—[a]	—[a]	—[a]
Hunting	V64	—[a]	—[a]	—[a]
5. Boat length (overall)	V14	***	***	—
6. Air temperature	V67	—	—	—
7. Weather conditions	V68	—	—	—
8. Wind conditions	V69	*	**	—
9. Boater (evaluator) age	V3	—	**	—
10. Boater (evaluator) sex	V4	**	—	—
11. Number of hours boating experience	V11	*	—	—
12. Principal location of boating activities	V12	***	—	—
13. Boater's (evaluator's) customary rate of PFD wear	V29	***	**	—
14. Evaluator's attitudes on PFD accessibility	V30, V38	—	***	—
15. Evaluator's attitudes about wearing PFDs in rough conditions	V31, V35, V41, V45	**	*	—
16. Evaluator's attitudes about the effectiveness and reliability of PFDs in general	V32, V37, V42	*	***	—
17. Image (how the evaluator feels about wearing PFDs in general and how he regards other who wear PFDs)	V34, V36, V39, V40, V48, V49, V50, V51	—	—	—
18. Evaluator's attitudes relating to whether he or she needs a PFD in the water	V33, V44, V46, V52	—	***	—
19. Evaluator's attitudes about PFD wear	V47, V43	—	—	—

a None of the wearability study participants reported engaging in these activities.

b PFDs were categorized into 5 types according to functional and design criteria.

c * means $p < 0.10$
** means $p < 0.05$
*** means $p < 0.01$

Each of the above situational variables was also crosstabulated with the types of PFDs evaluated to insure that any association between situational variables and F_W or F_A could not be attributed to any difference in the types of PFDs evaluated in different situations.

These situational variables which were significantly ($p < 0.10$) associated with the wearability or accessibility factors were included in a multiple regression analysis.

The factors (F_W, F_A) were each regressed independently on the selected situational variables and entered into a regression equation in a stepwise manner. At each step the variable which accounted for the most unexplained variance was entered into the equation. The procedure stopped when none of the remaining variables accounted for at least 1% of the remaining variance. Summaries of the regression analyses are shown in Figure III-10. The column labeled "R SQUARE" is the proportion of variance of the dependent variable (F_W or F_A) accounted for by the independent variables entered on that step and previous steps. For wearability (F_W) boat length accounted for about 9.5% of the variance, followed by boater's attitude on effectiveness and reliability of PFDs (NV11), boat type (V13) and the activity of fishing (V54). Together these variables accounted for over 19% of the variance in F_W. For accessibility (F_A) the boater's attitude on accessibility of PFDs (NV9) accounted for the most variance (17%), followed by boat length and the boater's attitude on PFD wear (NV14). These three variables together accounted for nearly 23% of the variance in F_A.

The multiple regression analyses generated regression equations for F_W and F_A:

$$F_W' = -0.086\ (V14) + 4.297\ (NV11) - 0.298\ (V13) - 0.855\ (V54) + 3.236$$

$$F_A' = 3.865\ (NV9) - 0.038\ (V14) + 0.949\ (NV14) - 2.445$$

A part of the variation in F_W and F_A scores for each PFD can be removed by adjusting each score to our best estimate of what it would have been if it had been evaluated under average or standard conditions. The equations for corrected values of F_W and F_A are:

WEARABILITY DATA ANALYSIS 11/23/77 PAGE 11

FILE TED (CREATION DATE = 11/23/77) DOLL PFD

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. WRBLTY

S U M M A R Y T A B L E

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	V14		14.13478	.000	.30786	.09478	.09478	-.30786	14.13478	.000
2	NV11		8.57270	.004	.38627	.14921	.05443	.25697	11.75018	.000
3	V13		4.80651	.030	.42295	.17888	.02967	-.15908	9.65815	.000
4	V54		2.10713	.149	.43793	.19178	.01290	-.22993	7.83069	.000

RESIDUALS - 179 CASES WRITTEN ON FILE BCDOUT

WEARABILITY DATA ANALYSIS 11/23/77 PAGE 15

FILE TED (CREATION DATE = 11/23/77) DOLL PFD

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. ACSBLTY

S U M M A R Y T A B L E

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	NV9		28.33686	0	.41652	.17349	.17349	.41652	28.33686	0
2	V14		7.54212	.007	.46640	.21753	.04404	-.26757	18.62609	.000
3	NV14		2.09981	.150	.47926	.22969	.01216	.24917	13.21925	0

RESIDUALS - 179 CASES WRITTEN ON FILE BCDOUT

FIGURE III-10. REGRESSION ANALYSIS

$$F_{W_c} = F_W + \beta_1 (\overline{X}_1 - X_1) + \dots + \beta_N (\overline{X}_N - X_N)$$

$$F_{A_c} = F_A + \alpha_1 (\overline{X}_1 - X_1) + \dots + \alpha_N (\overline{X}_N - X_N)$$

where F_{W_c} = the corrected wearability factor score for a specified PFD evaluation.

F_W = the unadjusted wearability factor score for the same evaluation.

α, β = regression coefficients relating each independent variable to F_W or F_A, e.g., the coefficient relating V14 to F_W is -0.086.

$\overline{X}_1, \dots, \overline{X}_N$ = the average or a selected standard value of the (1st,....,Nth) independent variables in the regression equation for F_W or F_A

F_{A_c} = the corrected accessibility factor score for a specified PFD evaluation.

F_A = the unadjusted accessibility factor score for that PFD evaluation.

$X_1, \dots, X_N$ = the values of the 1st,....,Nth situational variables during the specified PFD evaluation.

Substituting in the appropriate values, we have:

$$\begin{aligned} F_{W_c} = F_W &- 0.086 \ (25.475 - V14) \\ &+ 4.297 \ (0.478 - NV11) \\ &- 0.298 \ (5.267 - V13) \\ &- 0.855 \ (1.721 - V54) \end{aligned} \qquad (13)$$

$$\begin{aligned} F_{A_c} = F_A &+ 3.865 \ (0.762 - NV9) \\ &- 0.038 \ (25.475 - V14) \\ &+ 0.949 \ (0.419 - NV14) \end{aligned} \qquad (14)$$

The corrected wearability and accessibility factor score are tabulated for each PFD tested in Table III-13.

The standard errors of the corrected wearability and accessibility scores are:

$$s_{e_{W_c}} = s_{e_W} \sqrt{1-R_W^2}$$

$$s_{e_{A_c}} = s_{e_A} \sqrt{1-R_A^2}$$

where R_W = the multiple correlation of F_W with V14, NV11, V13 and V54 = 0.438
R_A = the multiple correlation of F_A with NV9, V14, and NV14 = 0.479

The 90% confidence intervals for the corrected wearability and accessibility factors are:

$$\overline{F}_{W_c} \pm 1.645 \frac{s_{e_W} \sqrt{1-R_W^2}}{\sqrt{N}} \quad \text{and} \quad \overline{F}_{A_c} \pm 1.645 \frac{s_{e_A} \sqrt{1-R_A^2}}{\sqrt{N}}$$

For example, the 90% confidence interval for F_{W_c} for the first Type III vest listed in Table III-13 is (0.34, 3.20)*.

* Note that this confidence interval is based on a sample size of N=4 available observations. The interval given for uncorrected wearability on page III- 76 is based on N=6 observations.

4.6 Computation of Wearability and Accessibility Indices

The wearability index (I_W) and accessibility index (I'_{AC}) are estimates of the probability that a specified PFD will be worn and kept accessible, respectively. They must, therefore, take a value between 0 and 1.0. In order to meet this requirement, I_W and I'_{AC} were defined as simple transformations of the adjusted wearability and accessibility factors, F_{W_c} and F_{A_c}:

$$I_W^* \equiv \frac{F_{W_c} - F_{W_{THR-MAX}}}{F_{W_{MAX}} - F_{W_{MIN}}}$$

$$\text{for } F_{W_{THR-MAX}} \leq F_{W_c} \leq F_{W_{MAX}} - F_{W_{MIN}} + F_{W_{THR-MAX}}$$

$$I_W \equiv 0 \text{ for } F_{W_c} < F_{W_{THR-MAX}}$$

$$I_W \equiv 1.0 \text{ for } F_{W_c} > F_{W_{MAX}} - F_{W_{MIN}} + F_{W_{THR-MAX}}$$

where $F_{W_{MAX}}$ = the greatest possible unadjusted wearability factor score = 7.13

$F_{W_{MIN}}$ = the smallest possible unadjusted wearability factor score = -4.81

$F_{W_{THR-MAX}}$ = the theoretical maximum adjusted wearability factor which a throwable device can achieve = -1.69. This value is taken as the zero point for I_W.

$$I'^*_{AC} \equiv \frac{F_{A_c} - F_{A_o}}{F_{A_{MAX}} - F_{A_{MIN}}} \quad \text{for } F_{A_o} \leq F_A \leq F_{A_{MAX}} - F_{A_{MIN}} + F_{A_o}$$

$$I'_{AC} \equiv 0 \text{ for } F_{A_C} < F_{A_o}$$

$$I'_{AC} \equiv 1.0 \text{ for } F_{A_C} > F_{A_{MAX}} - F_{A_{MIN}} + F_{A_o}$$

---

* Note that both I_W and I'_{AC} can assume any value in the interval (0,1) since F_{W_c} is not limited to 7.13 (the maximum value of F_W) and F_A is not limited to 3.41 (the maximum value of F_A). For example, suppose F_W=6.5, V14=45.0, NV11=0, V13=8.0, and V54=1.0 (all of which are achievable values). Then from equation (13), F_{W_c}=10.43.

where $F_{A_{MAX}}$ = the greatest possible unadjusted accessibility factor score = 3.41

$F_{A_{MIN}}$ = the smallest possible unadjusted accessibility factor score = -6.51

F_{A_0} = the adjusted accessibility factor score taken as the zero point for I'_{AC} based upon comparison of the present data and results of the observational study = -4.03.

Note that the minimum wearability and accessibility factor scores ($F_{W_{MIN}}$, $F_{A_{MIN}}$) were not chosen as the zero points for I_W and I'_{AC}, respectively. Neither F_W nor F_A are ratio scales of measurement; that is, neither variable has a true zero point. The zero points must therefore be defined by using information other than the properties of the variables themselves (i.e., boundary conditions). In the case of the wearability index this was done by making the zero point correspond to the theoretical maximum wearability factor which a throwable can achieve. It was assumed that a throwable device will virtually never be worn before entering the water; therefore, its wearability factor score (F_W) should correspond to a wearability index of zero (I_W = 0). The theoretical maximum wearability factor for a throwable ($F_{W_{THR-MAX}}$ = -1.69) was determined by assigning each variable which contributes to F_W the most favorable value that a throwable could achieve, assuming that the evaluator followed instructions and responded to the actual wording of each question. These values are shown below:

VARIABLE	THEORETICAL MAXIMUM FOR THROWABLES
NV1	0
V106	1
V103	1
V78	1
V85	6
V91	2
V98	2
V109	6
V110	2
V89	1
V76	1
V97	5

The zero point for the accessibility index was establushed by comparing the corrected accessibility factor scores for throwables to the observed accessibility of throwables in the observational study. The average corrected accessibility factor for throwables ranged from a low of 0.29 for ring and horseshoe buoys to 1.24 for cushions. From the observational study, the ratio of the number of throwables kept accessible to the number of board was estimated to be between 0.37 and 0.44. A lower bound for the zero point of I'_{AC} was obtained by making the lowest I'_{AC} for throwables (0.29) correspond to the highest ratio of throwables accessible on board from the observational study (0.44). An accessibility factor score (F_A = -4.03) corresponds to an accessibility index (I_{AC}) of zero.

The indices of wearability and accessibility are tabulated for each PFD model tested in Table III-13. No index can be computed for those PFD evaluations on which values for any variable contributing to I'_{AC} or I_W was missing. Consequently, the sample sizes (Ns) for I_W, I'_{AC}, F_{W_c}, and F_{A_c} are often small and the estimated factors and indices may be subject to considerable variation.

The 90% confidence limits for the wearability and accessibility indices are computed as follows:

$$\bar{I}_W \pm 1.645 \frac{s_{e_W} \cdot \sqrt{\frac{(1-R_W^2)}{N}}}{F_{W_{MAX}} - F_{W_{MIN}}}$$

and $$\bar{I}'_{AC} \pm 1.645 \frac{s_{e_A} \cdot \sqrt{\frac{(1-R_A^2)}{N}}}{F_{A_{MAX}} - F_{A_{MIN}}}$$

where $\bar{I}_W$ = the average wearability index for a sample of N evaluations of a specified PFD model.

$\bar{I}'_{AC}$ = the average accessibility index for a sample of N evaluations of a specified PFD model.

Confidence intervals for I_W and I'_{AC} are tabulated for various sample sizes (Ns) at the bottom of Table III-13. Note that the confidence limits become smaller (accuracy increases) as the sample size is increased. For the wearability index a sample size of 6 evaluations is sufficient to estimate I_W within $\pm$ 0.10 with a confidence of 90%. For example, the red and white Davy Belt has a wearability (I_W) of 0.28 $\pm$ 0.10 with a confidence of 90%.

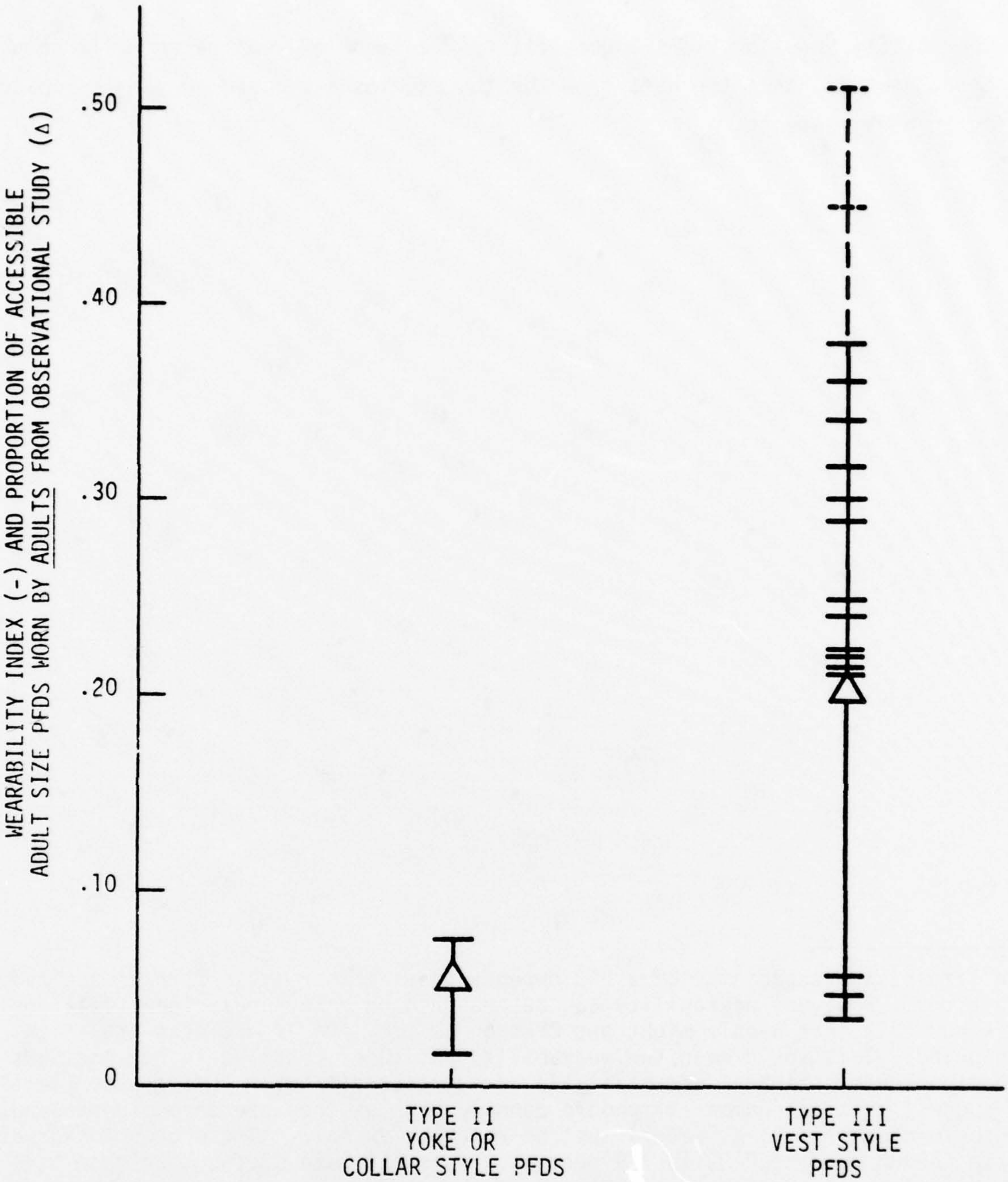
The accuracy of estimation of I_W and I'_{AC} can be further enhanced by increasing the number of evaluations (N) in the sample and/or by increasing the amount of data collected on each evauations. For example, each boater could be asked to evaluate the PFD on each of two outings. The second outing should be no less than one week after the first so that the boater does not remember the exact ratings he or she gave the PFD on the first occasion. This additional data would increase the level of accuracy of I_W to approximately ±0.069 for a sample size (N) of six evaluators. A sample size of N=12 evaluators would bring the accuracy of I_W to within +0.05 if each evaluator rated each PFD on two outings.

Figure III-11 compares the wearability indices for selected PFDs to observed wear rates from the nationwide observational study (see Section 3.0). Only two types of PFDs were observed with high enough frequency to allow comparisons. These were Type II yoke or collar style PFDs and Type III vest style PFDs. It was not generally possible to identify the PFDs by manufacturer and model in the observational study, hence only rough comparisons are possible. The wearability indices (indicated by horizontal lines) for the two most common Type II PFDs are in close agreement with the results of the observational study. The AK-1 and the yoke style foam Type II PFD had wearability indices of 0.07 and 0.02, respectively. This compares to a wear rate from the observational study of 0.056. The wearability indices for Type III vests show great variability from a high of 0.51 to a low of 0.03. The two Type III vests with the highest wearability indices (0.51 and 0.45) are colorful models which came onto the market relatively recently. The Type III vests in the observational study (conducted in 1975) were older, more conservative models. The top two wearability indices for Type III vests in Figure III-11 were probably therefore not represented in the observational study. The remaining Type III vests have wearability indices ranging from 0.38 to 0.03. The observational study shows an average wear rate for Type III vests of 0.202. These comparisons suggest that

the wearability index provides a good fit to "real-world" wear rates.[1] It should be noted, however, that the data from the two studies are based on samples which differ in many respects.

---

[1]The life-saving capability of a PFD depends upon whether it is worn in accident situations. However, wearability can be measured only in non-accident settings. It is possible that people might put PFDs on as they see an accident situation developing. This would mean the wearability estimates obtained in non-accident conditions underestimate wearability in accident conditions. ARM results (Section VI) suggest that the number of people donning PFDs as they see an accident developing (before entering the water) must be relatively small. The proportion of all people in ARM wearing PFDs is 7.9 percent. This estimate of the wear rate is probably slightly high because PFD wear is associated with severe circumstances and such conditions (e.g., fatal accidents) are over-represented in ARM. From the observational study (paragraph 3.0), when the distribution of ages is forced to match that of ARM victims, the overall wear rate is approximately 4.6%. Thus, the difference in wear rates between normal boating and accident conditions is probably no more than 3.3 percent. This result suggests that wearability estimates derived from normal boating conditions should be reasonably accurate in accident circumstances.



NOTE: THE WEARABILITY INDICES (-) SHOWN ARE ESTIMATES OF THE PROBABILITY THAT THE PFD WILL BE WORN GIVEN THAT IT IS ON BOARD, WHILE THE OBSERVATIONAL WEAR RATES ARE THE PROBABILITY THAT THE PFD WILL BE WORN GIVEN THAT IT IS ACCESSIBLE. IN ORDER TO MAKE THE TWO MEASURES COMPARABLE, OBSERVATIONAL DATA FROM LARGE CABIN TYPE BOATS WHERE MANY MORE PFDS COULD BE ON BOARD THAN ARE ACCESSIBLE HAVE BEEN EXCLUDED. SINCE THE WEARABILITY INDICES ARE FOR ADULT EVALUATIONS ONLY IN THIS STUDY, OBSERVATIONAL DATA FOR ADULTS ONLY HAS BEEN USED FOR COMPARISON.

FIGURE III-11. COMPARISON OF OBSERVATIONAL STUDY AND WEARABILITY STUDY RESULTS

Alternate methods for computing the wearability and accessibility indices were also investigated. According to the alternate method, I_W and I'_{AC} are defined as follows:

$$I_W = \frac{F_{W_C} - F_{W_{THR-MAX}}}{F_{W_{C_{MAX}}} - F_{W_{THR-MAX}}}$$

$$I_W \equiv 0 \text{ for } F_{W_C} < F_{W_{THR-MAX}}$$

and

$$I'_{AC} = \frac{F_{A_C} - F_{A_O}}{F_{A_{C_{MAX}}} - F_{A_O}}$$

$$I'_{AC} \equiv 0 \text{ for } F_{A_C} < F_{A_O}$$

where $F_{W_{C_{MAX}}}$ and $F_{A_{C_{MAX}}}$ are computed by using equations (13) and (14). In order to compute a maximum value for F_{W_C} and F_{A_C}, one must select a maximum value for V14, boat length. In these computations it has been assumed that the maximum value of V14 is 65 ft. Values of the other parameters in equations (13) and (14) which are used to compute $F_{W_{C_{MAX}}}$ and $F_{A_{C_{MAX}}}$ are:

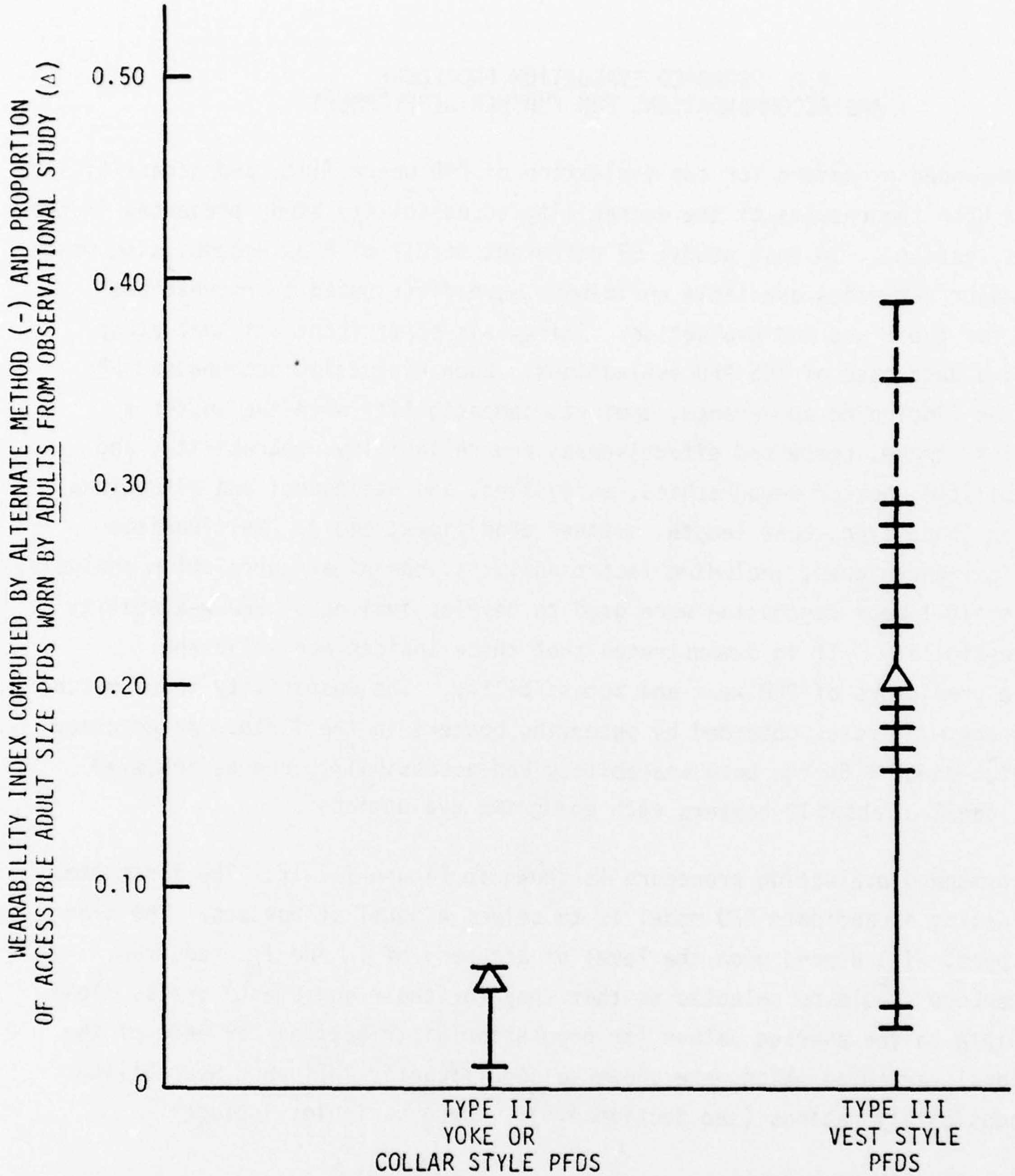
NV11	=	0
V13	=	8.0*
V54	=	2.0*
NV9	=	0
NV14	=	0

* Variables V13 and V54 were coded as follows in this analysis:

V13 Code	Boat Type	V54 Code	Activity
01	Canoe	01	Fishing
02	Inflatable	02	Not fishing
03	Other		
04	Sail		
05	Open Manual		
06	Open Power		
07	Cabin Motorboat		
08	Houseboat		

Using these values, $F_{W_{c_{MAX}}} = 13.64$ and $F_{A_{c_{MAX}}} = 8.25$. These alternate methods for computing I_W and I'_{AC} have the effect of reducing the higher values of I_W and I_{AC} shown in Table III-13 while leaving the lower values virtually unchanged. For example, the highest I_W for a Type III vest is 0.51 in Table III-13. This value becomes 0.39 using the alternate method. The wearability of the first Type II listed in Table III-13 is 0.02. Under the alternate method, this becomes 0.01. The highest value of I'_{AC} in Table III-13 goes from 0.62 to 0.50 using the alternate. The lowest value of I'_{AC} in Table III-13 is 0.04 and remains at that value under the alternate method.

Figure III-12 compares the alternate method for computing the wearability index to the observational data. More detailed observational data is needed to determine how to best scale the wearability and accessibility indices.



NOTE: THE WEARABILITY INDICES (-) SHOWN ARE ESTIMATES OF THE PROBABILITY THAT THE PFD WILL BE WORN GIVEN THAT IT IS ON BOARD, WHILE THE OBSERVATIONAL WEAR RATES ARE THE PROBABILITY THAT THE PFD WILL BE WORN GIVEN THAT IT IS ACCESSIBLE. IN ORDER TO MAKE THE TWO MEASURES COMPARABLE, OBSERVATIONAL DATA FROM LARGE CABIN TYPE BOATS WHERE MANY MORE PFDS COULD BE ON BOARD THAN ARE ACCESSIBLE HAVE BEEN EXCLUDED. SINCE THE WEARABILITY INDICES ARE FOR ADULT EVALUATIONS ONLY IN THIS STUDY, OBSERVATIONAL DATA FOR ADULTS ONLY HAS BEEN USED FOR COMPARISON.

FIGURE III-12. COMPARISON OF OBSERVATIONAL STUDY AND WEARABILITY STUDY RESULTS WITH I_W COMPUTED BY ALTERNATE METHOD

5.0 PROPOSED EVALUATION PROCEDURE AND RECOMMENDATIONS FOR FURTHER DEVELOPMENT

The recommended procedure for the evaluation of PFD wearability and accessibility is based upon the results of the wearability/accessibility study presented in the previous sections. In that study, 67 different models of PFDs encompassing most of the major varieties available world-wide were distributed to recreational boaters for their use and evaluation. Thirty-six participants in that study produced a data base of 185 PFD evaluations. Each evaluation encompassed PFD properties (including appearance, comfort, compatibility with the boater's activities, image, perceived effectiveness and reliability, wearability, and accessibility); boater demographics, activities, and attitudes; and situational variables (boat type, boat length, weather conditions, etc.). Multivariate statistical techniques, including factor analysis, canonical correlation analysis, and multiple linear regression were used to develop indices of PFD wearability and accessibility. It is demonstrated that these indices are valid and reliable predictors of PFD wear and accessibility. The wearability index matches closely the wear rates obtained by observing boaters in the field. An accuracy of prediction of $\pm$ 5% for both wearability and accessibility can be achieved using a panel of about 12 boaters each doing two evaluations.

The recommended evaluation procedure is shown in Figure III-12. The first step in evaluating a candidate PFD model is to select a panel of boaters. The size of the panel will depend upon the level of accuracy of I_W and I_{AC} required. Panel members should be selected so that they (or their equipment) are as close as possible to the average values (or population distribution) for each of the situational variables which were shown to significantly influence wearability and accessibility ratings (see Section 4.5). These variables include:

- Overall boat length.
- Boater's attitude on the effectiveness and reliability of PFDs in general.
- Boat type.
- Whether the boater's principal boating activity is fishing.
- Boater's attitude about keeping PFDs accessible.
- Boater's attitude about wearing PFDs.

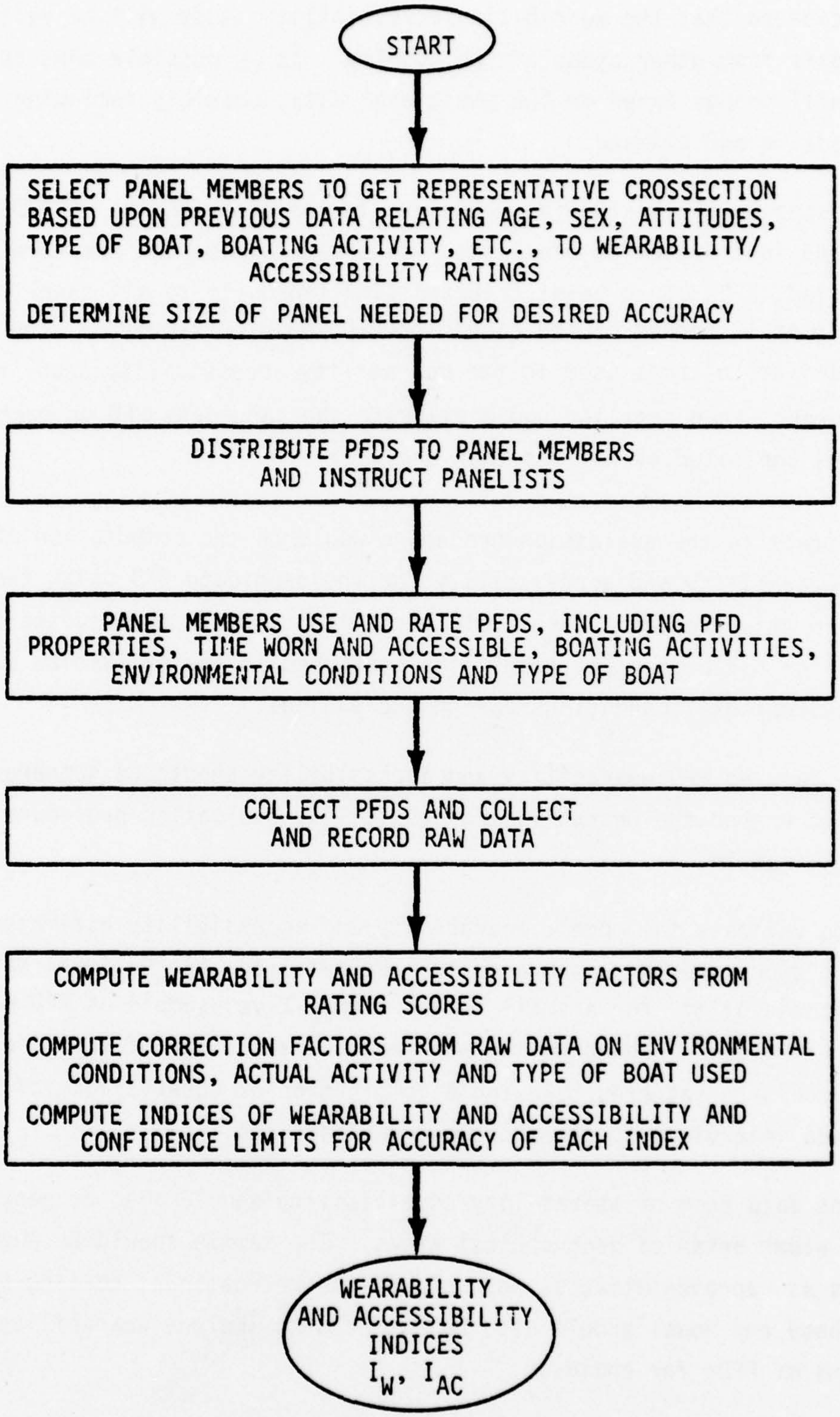


FIGURE III-13. PROPOSED PROCEDURE FOR THE EVALUATION OF PFD WEARABILITY AND ACCESSIBILITY

It is anticipated that the wearability/accessibility study will be validated by gathering data from other areas of the country. It is possible that this list of variables will change based on the additional data, possibly including factors such as location and climate.

The second step in the evaluation procedure is the distribution of PFDs to panelists and instruction of panelists. In order to minimize the time required for evaluation, PFDs could be distributed simultaneously to all panel members. On the order of 12 copies of the candidate PFD would be required. The instructions would be similar to those used in the wearability/accessibility study reported above. However, each panelist would evaluate the candidate PFD on each of two boat outings separated by no less than one week.

The final steps in the evaluation procedure would be the computation of the estimated wearability and accessibility for the candidate PFD using the formulas developed in this project. Each evaluator's inputs would be adjusted to compensate for his or her attitudes, the boat used in the evaluation outings, and the environmental conditions during the outings.

Additional data on PFD wearability and accessibility should be gathered to validate and extend the wearability/accessibility evaluation procedure and mathematical models.

In order to validate the model, wearability and accessibility estimates from the present study should be compared to more detailed observational data on wear and accessibility for a small (e.g., twenty-five) sample of PFD models. Observational data is needed on the wear and accessibility of <u>specific PFD models</u>. This data could be gathered by using a combination of observations of boaters underway and interviews at launch ramps, marinas, etc.

The present data base of wearability/accessibility should also be generalized to include a wider array of geographical areas. The sample should be augmented so that it is as representative as possible of the recreational boating population. The data base and model should also be extended to include wearability/accessibility evaluations of PFDs for children.

REFERENCES

1. United States Coast Guard, Boating Statistics 1971, CG-357.

2. Dayton, R.B., Design Criteria for Advanced PFDs, Operations Research, Inc., ORI-TR-861, 1974. NTIS No. AD-A010-404.

3. Bryk, J.A. and Schupack, S.A., Boating Safety: The Use of Personal Flotation Devices, National Safety Council, USCG Grant No. 1301-92, 1974.

4. Operations Research, Inc., A Study of Factors Influencing the Wearability of PFDs in Recreational and Work Environments, CG-D-88-75, 1974. NTIS No. AD-A011-211.

5. Doll, T.J., et al., Personal Flotation Devices Research, Phase I. Wyle Laboratories, July, 1976. NTIS No. AD-A037 221/9GA.

6. Boating Industry Magazine, "The Boating Business, 1975," 1975.

7. Wulfsberg, R.M. and Lang, D.A., Recreational Boating in the Continental United States in 1973: The Nationwide Boating Survey, U.S. Coast Guard, Report No. 745103, 1974. NTIS No. AD-A000-471.

SECTION IV
PHYSICAL EFFECTIVENESS

TABLE OF CONTENTS

SECTION IV TABLE OF CONTENTS, Concluded

SECTION IV LIST OF FIGURES

SECTION IV LIST OF TABLES

SECTION IV
PHYSICAL EFFECTIVENESS

1.0 SUMMARY

The Life Saving Index (LSI) System combines the major components of wearability, effectiveness, and reliability into a model which can be used to evaluate the life saving capability of PFDs.

The purpose of this section is to provide a methodology for use in evaluating the physical effectiveness of a particular PFD design. Two methods were investigated for predicting PFD effectiveness: 1) measurement of general PFD properties, and 2) tests of PFDs using an anthropomorphic dummy. The results of the measurement for PFD properties and the results using the anthropomorphic dummy are compared to the human subject test results to find the best method for predicting PFD effectiveness.

The centers of buoyancy of PFDs were measured using a one-ring and three-ring system. Measurements were also made of total PFD buoyancy and buoyancy forward of the centerline. An analysis was made of the measurements to determine the forces acting in various PFD designs. These results were compared to the results of the human subject tests to determine whether the measured PFD properties could be used to predict PFD effectiveness. This comparison showed that inaccuracies in the one and three ring systems introduced measurement error affecting results.

Human subject testing of various PFDs for physical effectiveness parameters was performed. The results of this study produced information on the effectiveness of various PFDs on a wide range of subjects. The study permits a comparison of representative inherently buoyant, inflatable, and hybrid devices on effectiveness parameters. The results of this study have been used to develop and test alternative methods for predicting PFD effectiveness parameters.

PFD properties are compared to the performance of each PFD in the human subject experiments. One of the important results is that the Turning Moment Index, which is defined by the total buoyancy for each PFD and its center of buoyancy, correlates well with the performance of the human subjects in the Head Forward Moving Test.

Effectiveness testing using an anthropomorphic dummy is discussed. The details of the test methods are enumerated along with emphasis on precautions and limitations.

The predicted effectiveness using the Dummy Test Method is compared with the performance of each PFD in the human subject experiments. The dummy is shown to adequately predict the effectiveness of PFDs for providing an adequate turning moment and maintaining freeboard.

A recommended effectiveness test procedure concludes this section.

1.1 Introduction

The goal of the physical effectiveness component of the PFD Project is to develop a method for predicting or evaluating the effectiveness of existing and future PFD designs. The method should be sufficiently general and flexible so that it can be applied to PFD designs still in the conceptual stage, or at least to prototypes of advanced PFDs.

The physical effectiveness of a PFD when worn is defined as the probability that the device maintains or turns the wearer in the water to a position with a minimum required freeboard to the lower respiratory passage within a specified time limit. In order to satisfy this criterion, the device must: (a) have sufficient buoyancy, and (b) maintain the individual in a vertical or slightly backward-leaning orientation. The principal measure of orientation is the equilibrium angle, defined as the angle between vertical and the centerline of the wearer's body (see Reference 1 for definition of the centerline). The effectiveness of a PFD when held is defined as the probability that the PFD provides a minimum required freeboard to the lower respiratory passage for a relaxed person holding or lying upon the device in the water.

Previous research on physical effectiveness has been conducted by Arthur D. Little, Inc. (ADL) (Reference 1), Operations Research, Inc. (ORI) (Reference 2) and Underwriters' Laboratories (UL) (Reference 3). The previous work consists of an attempt to mathematically model the buoyancy of the human body and PFDs, and tests designed to validate the model. Unfortunately, the mathematical model has very little predictive power. The ORI report concludes:

> "....inherent inaccuracies in the measurements used in this work for the various vector quantities are too great to permit useful predictions of equilibrium angle using the flotation theory of Reference 1." (Reference 2)

Aside from the inability of the mathematical model to generate useful predictions, other problem areas in the approach of previous work have become apparent. The previous research focused exclusively on the effectiveness of PFDs when worn. However, studies conducted by Wyle Laboratories, ORI (Reference 4), and the National Safety Council (Reference 5) indicate that the rate of PFD wear is very low (e.g., the overall percentage of people wearing PFDs under normal conditions is approximately 7% according to the Wyle study). Since PFD wear is so low, it is very likely that and accident victim will not be wearing a PFD when he enters the water. Therefore, it is important to consider PFD effectiveness when held or donned by the victim after he enters the water.

It is also clear from previous research and accident investigations that victims often enter the water quickly and unexpectedly. Sudden impact with the water may cause a PFD to change position on the wearer's body and alter the PFD's effectiveness.

A third problem which should be addressed is the effect of body posture and configuration on effectiveness. For example, the position of the victim's head (whether held erect, forward, or back) and whether he adopts a relaxed, open position or closed, huddled position in the water will affect the ability of the PFD to provide the proper orientation and buoyancy.

1.2 Approach

Wyle's initial approach to the PFD effectiveness problem was to refine the human body buoyancy model formulated by Arthur D. Little, Inc. (Reference 1). In any modeling effort it is necessary to make certain assumptions in order to make the problem manageable. In the case of the human body buoyancy model a re-examination of some of the assumptions might lead to better predictive capability.

One specific area which Wyle addressed in this effort was the influence of physiological characteristics not accounted for in previous applications of the model. Most important of these was the relative separation and orientation of the center of gravity of the subject and his center of buoyancy.

The living human body is a dynamic system, so that its center of gravity location with reference to anatomical landmarks, over a period of time can be specified only with inherent uncertainty. If the body is undergoing acceleration or a change in attitude, the resultant shift of forces will further alter the center of gravity location.

Likewise, the center of buoyancy acts much like the center of gravity with the exception that it is the location of the center of gravity of the fluid displaced by the submerged portion of the body.

In water as in air, the body fluids are redistributed as the attitude changes. The lung volume changes as the individual breathes. The relative positions of the body segments change as the attitude in water changes. The living body even when unconscious, is a dynamic system and the center of gravity (CG) and center of buoyancy (CB) are constantly changing.

The Arthur D. Little, Inc. (ADL) (Reference 1) report on the buoyancy and stability characteristics of the human body in fresh water assumed a rigid body. However, mobility of the extremities can have a definite effect on the location of a body's center of gravity and center of buoyancy.

As Wyle began work on refining the human body buoyancy model, it soon became clear that a host of complicating factors would have to be taken into consideration before the model could generate useful predictions. At the same time it became obvious that the effectiveness problem is more general than that of supporting an unconscious wearer in the water. The low rate of wear of PFDs suggests the need for methods of evaluating the effectiveness of a PFD when held or donned in the water, as well as when worn. These considerations led to the formulation of a revised approach to PFD effectiveness. The new approach was presented in the second interim report on PFD research and approved by the Coast Guard Contract Monitor on 16 March, 1976.

The revised approach investigates two alternative avenues to development of a method for evaluating PFD effectiveness. One of these is a set of general design criteria for PFDs. The other is a test method which uses a human simulator or test dummy. A key characteristic of both of these methods is that they are

primarily empirical. The development of the method and the process of evaluating PFDs for approval is based upon laboratory test results. The methods involve no mathematical model and no assumptions about the buoyancy characteristics of the human body. The following report details the results of an evaluation of these two approaches to determining PFD effectiveness.

1.3 Test Facility and Apparatus

The test pool used for these tests is located at the Marine Technology building at the Wyle Huntsville Facility. The overall dimensions of the pool are 37 ft long x 10 ft wide x 12 ft deep and is represented in Figure IV-1. The pool has two depths, 12 ft and 5.5 ft, but only the deep end was used in these tests.

The pool was equipped with necessary photographic equipment as part of the data collection system. A grid surface was placed against one side of the pool to provide a measurement background which could be used for subsequent data analysis/reduction and which would be accessible directly from the photographs. Finally, a block and tackle system was used for lifting the dummy in and out of the water, and when connected to the strain gauge, provided a means for weighing.

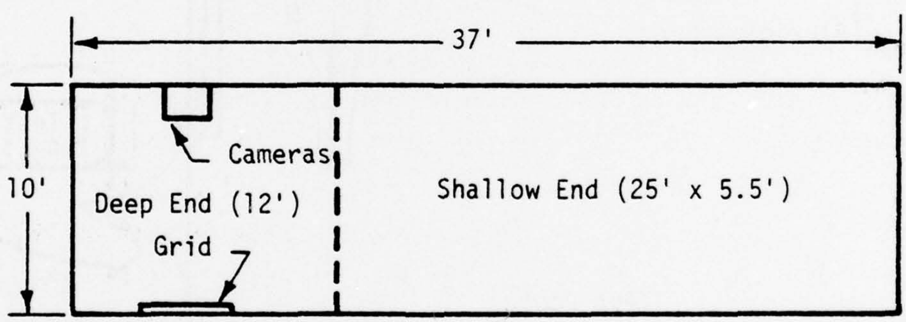


FIGURE IV-1. PLAN VIEW OF THE TEST POOL SHOWING THE DIMENSIONS AND ARRANGEMENT OF EQUIPMENT

1.3.1 Photographic Equipment

Two 35mm still frame cameras were mounted in a flexiblas box which was approximately 3/4 submerged in the test pool (see Figure IV-2). One camera was mounted so that underwater shots could be taken of the test activity, and the other camera (wide angle lens) was mounted to take above water photographs. The underwater shots were to be used in determining the final or resting equilibrium angle of the dummy, while the above water shots (in conjunction with the grid pattern) showed the amount of freeboard provided by each PFD. The photographs were taken against a grid pattern laid out in two inch squares and affixed to one side of the test pool.

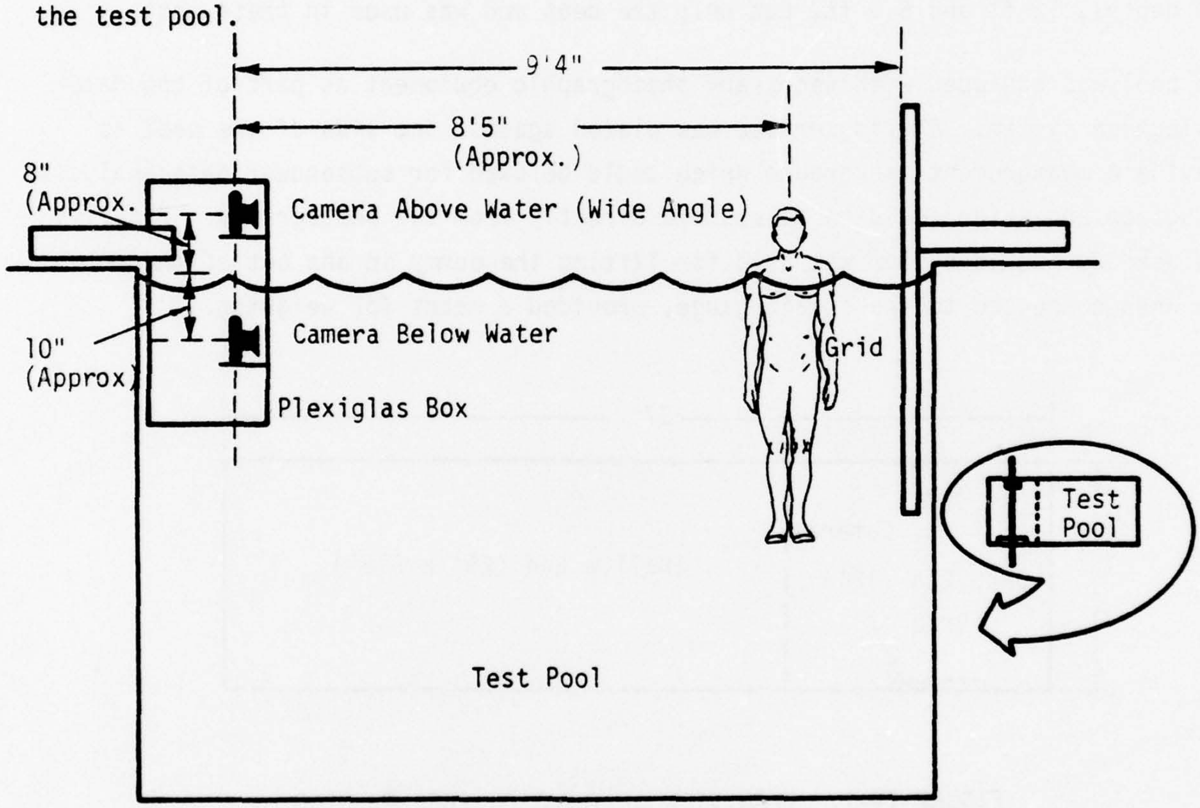


FIGURE IV-2. TEST POOL SHOWING THE LOCATION OF PHOTOGRAPHIC EQUIPMENT (NOT IN PROPORTION) (CROSS-SECTION VIEW)

1.3.2 Lifting Apparatus

A block and tackle system (consisting of two pulleys, rope, and a hook) attached to the ceiling above the deep end of the tank was used for lifting the dummy in and out of the pool. The dummy harness was composed of two tethers affixed at the shoulder. When it became necessary to lift the dummy, the block and tackle was hooked through the harness.

1.3.3 Weighing Apparatus

When weight measurements were necessary, a strain gauge was attached to the lifting apparatus. Weight values were exhibited on the digital display. The strain gauge was "zeroed" at its low end (0 lb) and at its high end (250 lb). A calibrated weight was attached to the gauge to verify the setup procedure. During the testing, the gauge was disconnected from the lifting apparatus and set aside (Figure IV-3).

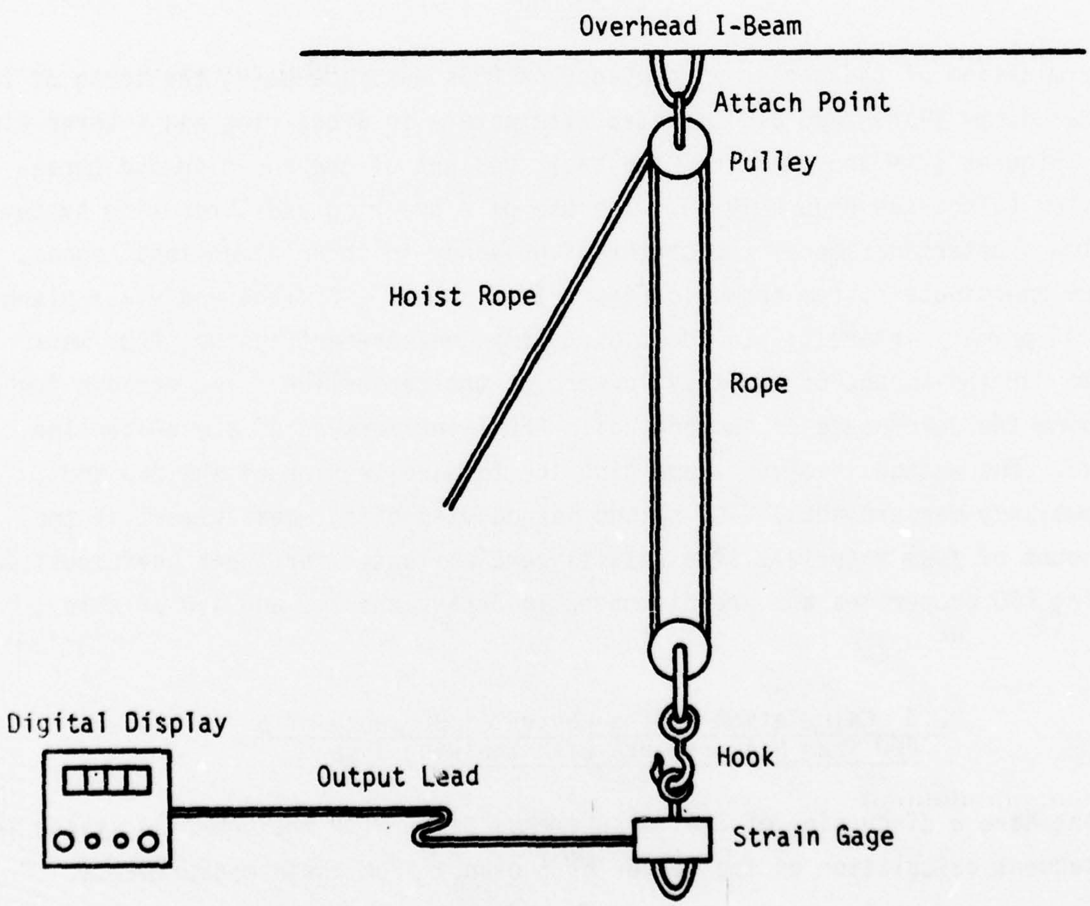


FIGURE IV-3. LIFTING APPARATUS SHOWN WITH STRAIN GAGE ATTACHED

2.0 MEASUREMENT OF PFD PROPERTIES

2.1 Purpose

The purpose of this section is to provide an evaluation of methodology for determining the center of buoyancy of a PFD. The method employed the use of a framework consisting of three concentric rings attached such that they could move independently to form a 3 axis coordinate system in space, thus allowing a completely submerged PFD to rotate naturally in the water and assume its normal orientation. This normal orientation would be a function of the center of buoyancy of a particular PFD design. The results from the measurement of the center of buoyancy of a PFD using this method can be compared to the actual performance of this PFD design under human subject testing (Paragraph 3.0). Based on this comparison, the validity of this method can be established and a range of values necessary for a desired level of performance can be derived.

2.2 Method

The determination of the center of buoyancy of PFDs was made using the torso of the Sierra Sam dummy (Paragraph 5.0) mounted alternately in a one-ring and a three-ring system. Figures IV-4 and IV-5 show the basic designs of the one-ring and three-ring system (also, see Figure IV-9). The use of a one-ring and three-ring system will allow a determination of the center of buoyancy in three dimensional space. Using the coordinate system shown in Figure IV-6, the x - z plane and y - z plane will be of primary interest. In addition to this measurement system, PFDs were evaluated for the amount of buoyancy forward of the centerline. Two methods for determining the percentage of buoyancy of a PFD lying forward of the centerline were used. One method involved submerging the forward section of the PFD and taking buoyancy measurements. The second method used direct measurement of the total amount of foam material. The results were evaluated for their usefulness in predicting PFD properties and are discussed in Paragraphs 3.0 and 4.0 of this section.

2.3 Calculation of the Center of Buoyancy of a PFD from Measurements with the Ring System

We present here a discussion of the measurements taken with the one-ring system and the subsequent calculation of the center of buoyancy from these measurements.

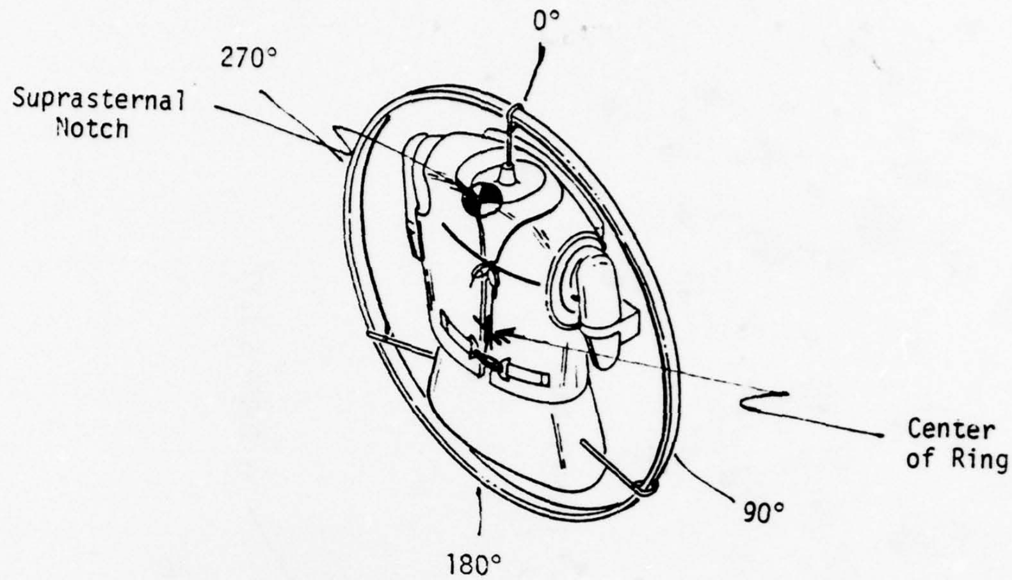


FIGURE IV-4. ONE-RING SYSTEM

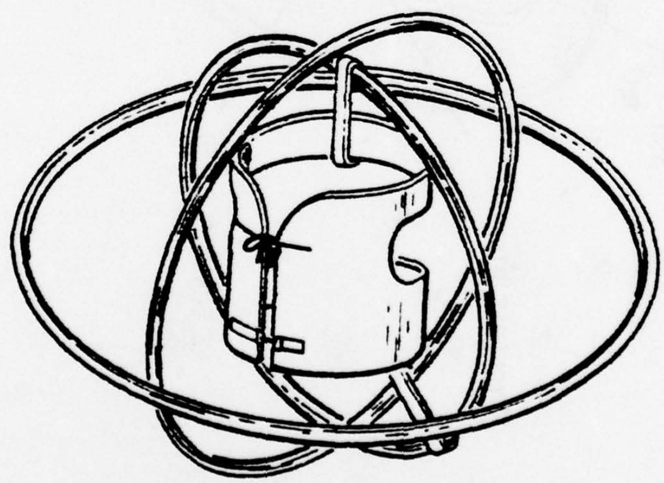
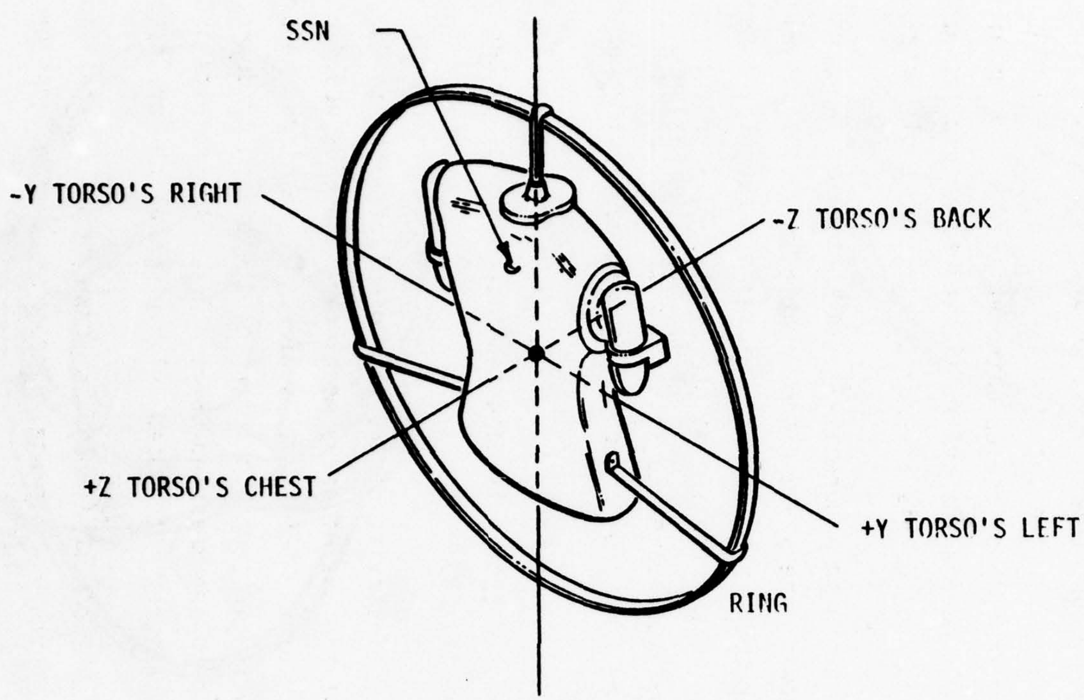


FIGURE IV-5. THREE-RING SYSTEM



O = ORIGIN IN CENTER AND IN PLANE OF RING

SSN = TORSO'S SUPRASTERNAL NOTCH

FIGURE IV-6. COORDINATE SYSTEM

The center of buoyancy measurements are basically determined from the angle that a PFD forces the torso/ring system to take in the water. The torso/ring system is to be attached to the bottom of the tank and weights/flotation added to this torso/ring system so it becomes a neutrally buoyant and stable apparatus in any position. A PFD is then attached to this system and the whole system again allowed to assume its natural position. A photograph is taken of the system in this position. The angle (θ) from the vertical line that the PFD has forced the ring to assume, is needed for the determination of the CB mathematically. The entire system is then inverted 180° and twisted and the system allowed to assume its natural position. A photograph is again taken of this arrangement and the angle measured.

This arrangement is shown in Figure IV-7. In this case, two photographs were taken along the x-axis showing the y - z plane. Taking a photograph along the x-axis is equivalent to looking down from above the torso's neck. The intersecting lines in Figure IV-7 represent the extension of the (vertical) rope attached to a weight which keeps the apparatus submerged in each of the two photographs. The line obtained by extending the rope in each photograph passes through the CB if two conditions are met:

1. The ring-torso system is adjusted such that its center of gravity coincides with its CB.

2. The center of gravity of the PFD coincides with its CB. It was recognized that the use of heavy metal parts on PFDs would affect the center of gravity of the PFD and thus affect CB readings. A brief investigation was conducted in order to determine the effect of departures from the assumption on the measured CB of a PFD. The results showed that considerable departures introduced only very small error in the measured CB.*

Since we know that each of two lines pass through the CB, their intersection is the location of the CB in the y - z plane. The intersecting lines can be represented by:

$$z = m_1 y + c_1 \tag{1}$$

$$z = m_2 y + c_2 \tag{2}$$

---

* The authors express their appreciation to Wilco Van der Linden for conducting this analysis and for conducting the tests of the centers of buoyancy of PFDs.

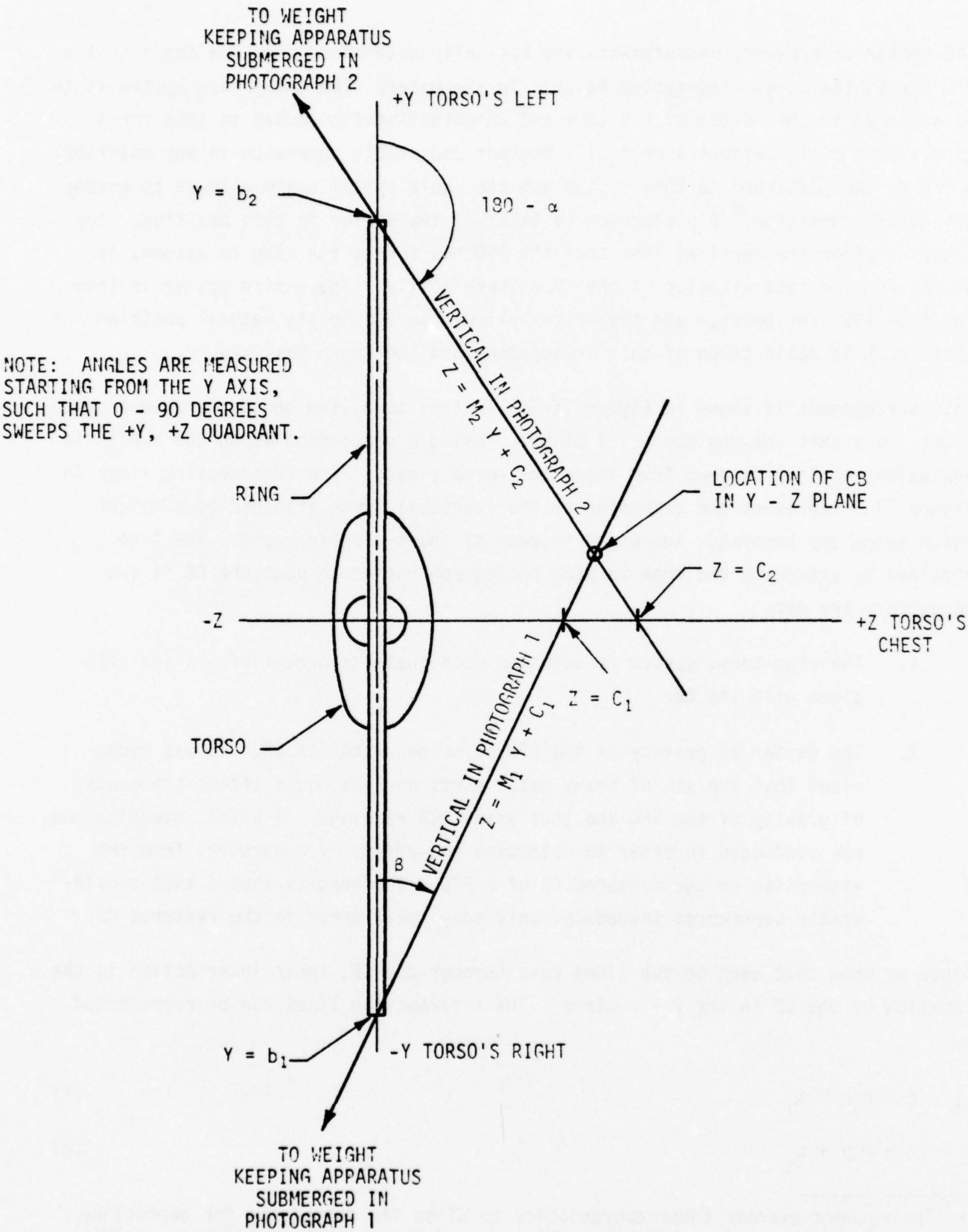


FIGURE IV-7. VIEW OF THE Y - Z PLANE OF THE RING APPARATUS AND TORSO

The intersection of these two lines is described by:

$$y = \frac{c_1 - c_2}{m_2 - m_1} \qquad (3)$$

$$z = \frac{m_2 c_1 - m_1 c_2}{m_2 - m_1} \qquad (4)$$

The slope of each line is:

$$m_1 = \tan \beta$$

$$m_2 = \tan (180 - \alpha)$$

Setting $z = 0$ in Equation (1) and referencing Figure IV-5.

$$y = - \frac{c_1}{m_1} = b_1$$

Since $c_1 > 0$ and $m_1 > 0$, $b_1 < 0$

Setting $z = 0$ in Equation (2):

$$y = - \frac{c_2}{m_2} = b_2$$

Since $c_2 > 0$ and $m_2 < 0$, $b_2 > 0$

Rewriting the above equations:

$$c_1 = - b_1 m_1 = -b_1 \tan \beta$$

$$c_2 = -b_2 m_2 = -b_2 \tan (180 - \alpha)$$

Substituting these results into Equations (3) and (4):

$$y = \frac{-b_1 \tan \beta + b_2 \tan (180 - \alpha)}{\tan (180 - \alpha) - \tan \beta} \qquad (5)$$

$$z = \frac{(b_2 - b_1) \tan (180 - \alpha) \tan \beta}{\tan (180 - \alpha) - \tan \beta} \qquad (6)$$

These equations describe the intersection of the vertical lines which is the location of the CB in the y - z plane (see Figure IV-7).

Two additional photographs are taken along the y axis and show the x - z plane. These photographs are profile views of the torso as shown in Figure IV-8.

The intersection point of the vertical lines is:

$$x = \frac{c_3 - c_4}{m_4 - m_3} \qquad (7)$$

$$z = \frac{m_4 c_3 - m_3 c_4}{m_4 - m_3}$$

The slopes of the lines are:

$$m_3 = \tan \theta$$

$$m_4 = \tan (180 - \phi)$$

Setting z = 0 for line 3:

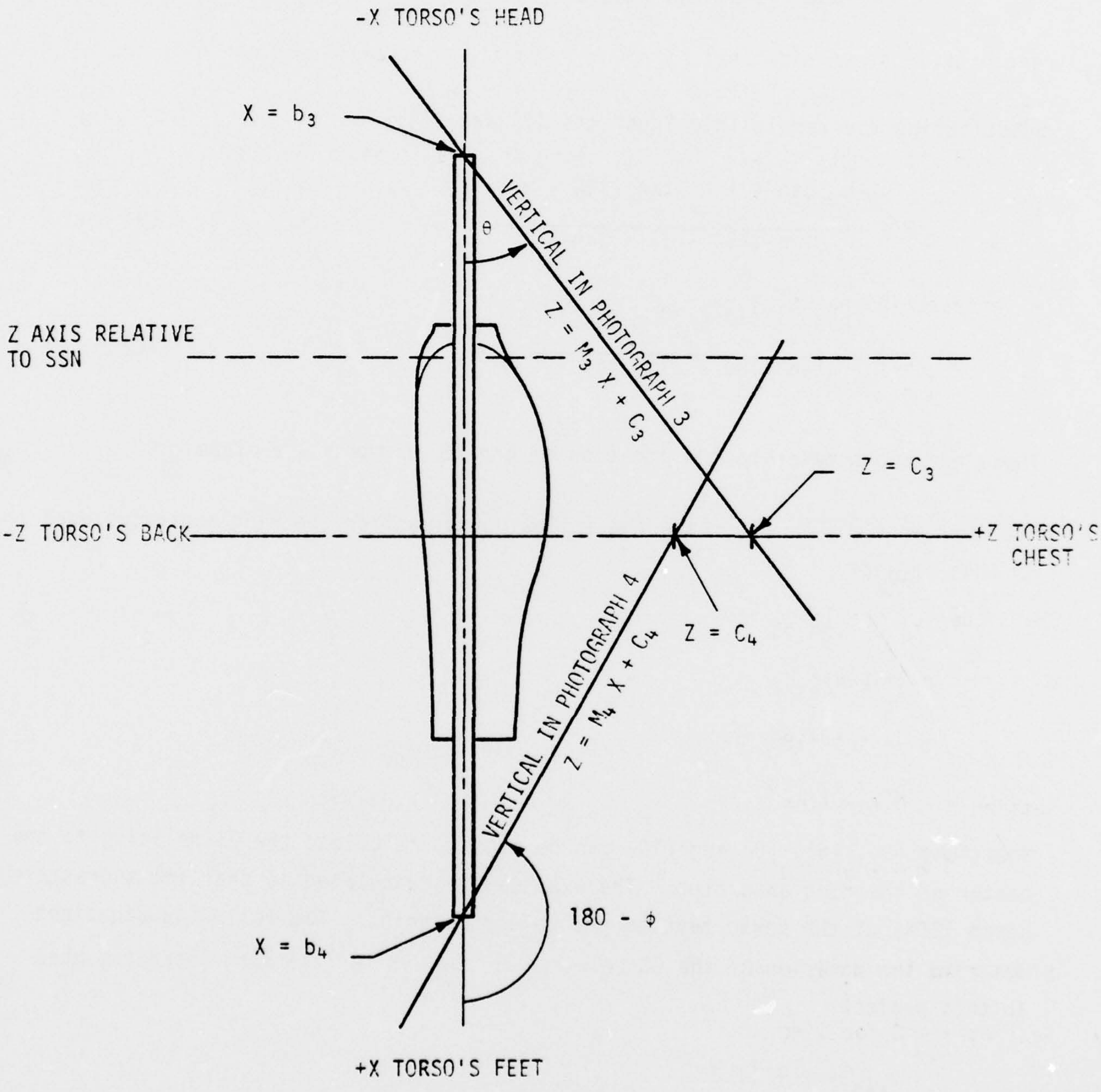
$$x = - \frac{c_3}{m_3} = b_3$$

Since $c_3 > 0$ and $m_3 > 0$, $b_3 < 0$

Setting z = 0 for line 4:

$$x = - \frac{c_4}{m_4} = b_4$$

Since $c_4 > 0$ and $m_4 < 0$, $b_4 > 0$



NOTE: ANGLES ARE MEASURED STARTING FROM THE X AXIS, SUCH THAT 0 - 90 DEGREES SWEEPS THE +X, +Z QUADRANT.

FIGURE IV-8. VIEW OF THE X - Z PLANE OF THE RING APPARATUS AND TORSO

Combining the above equations:

$$c_3 = -b_3 m_3 = -b_3 \tan \theta$$

$$c_4 = -b_4 m_4 = -b_4 \tan (180 - \phi)$$

Substituting the result into Equations (7) and (8):

$$x = \frac{-b_3 \tan \theta + b_4 \tan (180 - \phi)}{\tan (180 - \phi) - \tan \theta} \qquad (9)$$

$$z = \frac{(b_4 - b_3) \tan (180 - \phi) \tan \theta}{\tan (180 - \phi) - \tan \theta} \qquad (10)$$

These equations describe the location of the CB in the x - z plane.

The constants $b_1, \ldots, b_4$ have the following values for the ring apparatus used in this project:

$$b_1 = -20.94$$

$$b_2 = +20.94$$

$$b_3 = -21.44$$

$$b_4 = +21.44$$

Equations (5), (6), (9) and (10) can be used to calculate the CB relative to the center of the ring apparatus. The axes can be translated so that the suprasternal notch (SSN) of the torso becomes the reference point. The following equations describe the position of the CB relative to the SSN for the ring apparatus used in this project:

$$x_{ssn} = x + 11.81$$

$$y_{ssn} = y - 0.13$$

$$z_{ssn} = z$$

2.4 Results

Using the equations derived previously and the angles measured from the photographs, the center of buoyancy for various PFDs in three dimensional space was calculated. The results showed that all measurements in the x - y plane were insignificant, meaning that all PFDs were symetrical in distribution of flotation material or air chambers. Therefore, measurements of the CB of the PFDs was necessary only in the x - z plane. Accurate measurements of the z value were obtained using the one-ring system. However, due to the looseness of fit of various PFDs, it was necessary to employ the use of the three-ring system to obtain x values. The results from the measurement of the x and z values for various PFDs is shown in Table IV-1. Example photographs can be seen in Figure IV-9.

Several difficulties were encountered with the use of this measurement system. The ring systems used were found to be susceptible to three factors:

1. The use of photographs for measuring the relevant angles was found to introduce measurement error due to the distortion of the water and difficulty in obtaining pictures that were oriented properly.

2. It was discovered that due to the sensitivity of the ring measurement system any turbulence in the water would alter the system orientation, thus creating difficulty in obtaining reproducible results.

3. Even though every attempt was made to reduce friction in the ring system, the introduction of some error is probable due to the friction.

Due to these three factors, the accuracy of the system suffers and, therefore, exact reproducibility and an analysis of the results might be difficult. Any judgments based on the data from this system should be made using gross changes because minor changes may be due solely to the aforementioned errors.

TABLE IV-1. CALCULATED VALUES FOR CB OF VARIOUS PFDS

PFD	COORDINATES RELATIVE TO SSN		TOTAL BUOYANCY
	X	Z	
TYPE I STANDARD FOAM YOKE (366)[a]	+ 2.52	+2.21	27.4
TYPE II STANDARD FOAM YOKE (367)	+ 3.45	+2.43	18.1
TYPE II AK-1 (200)	+ 1.04	+1.59	15.7
TYPE III FOAM VEST (326, 327)	+ 3.54	+0.46	15.7
TYPE III FOAM FLOTATION JACKET (302, 370, 371)	+11.81	+0.61	18.7
TYPE III HYBRID VEST UNINFLATED (307)	+ 1.29	+1.13	15.6
TYPE III HYBRID VEST INFLATED (307)	- 0.11	+1.44	35.4
MODIFIED HYBRID VEST UNINFLATED (218)	+ 0.53	+0.51	9.5
MODIFIED HYBRID VEST INFLATED (218)	+ 5.69	+1.99	30.1
INFLATABLE YOKE (152)	+ 0.20	+2.02	18.0
INFLATABLE TUBE IN BELT (130)	+11.81	0	17.9
TYPE IV KAPOK CUSHION (178)	+ 9.42	+4.07	22.8

[a] Wyle Number - See Table IV-2 for description of each PFD.

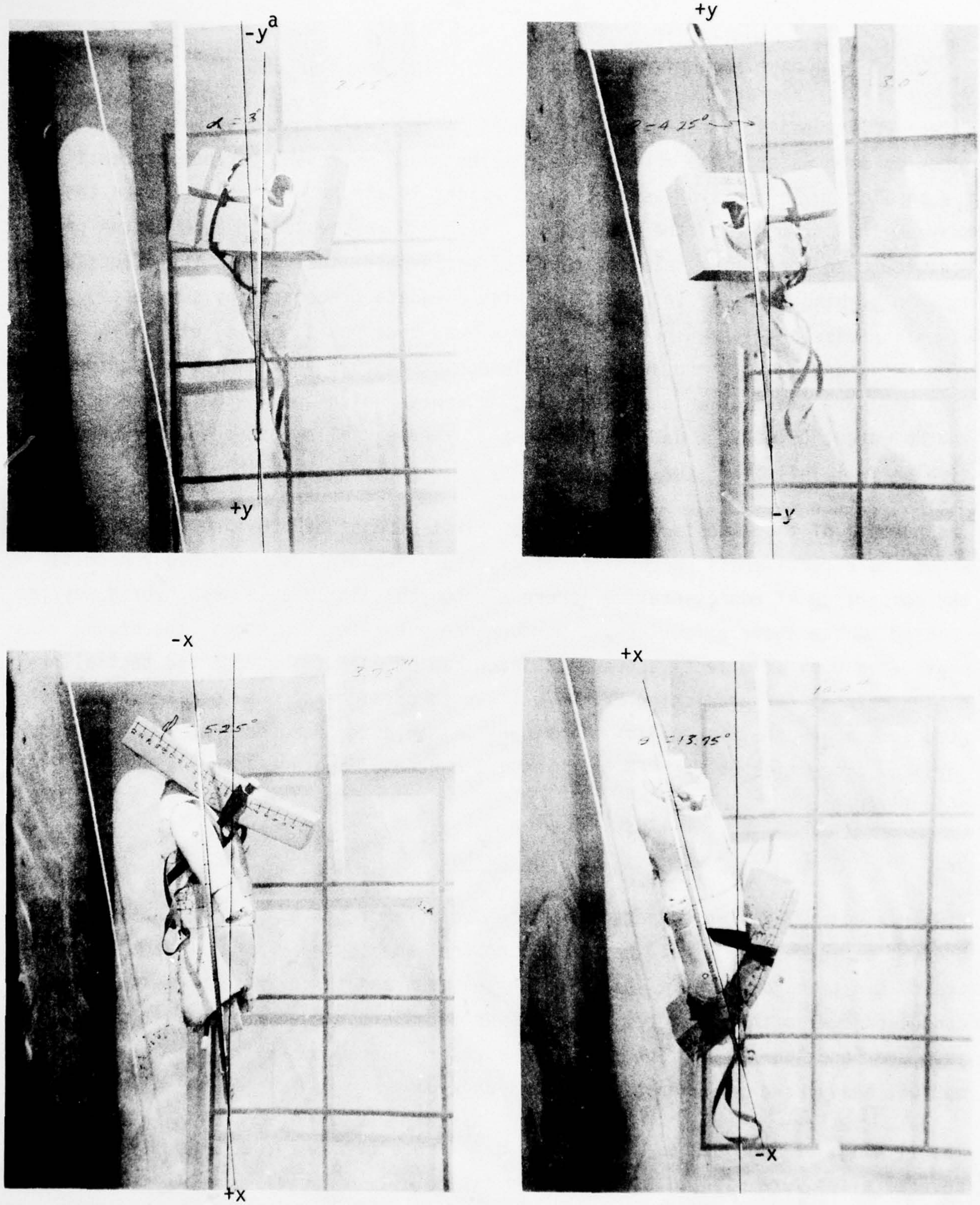


FIGURE IV-9. DETERMINING CB (ANGLES) FROM UNDERWATER PHOTOGRAPHS USING RING SYSTEM

[a] Axes relative to the center of the ring apparatus.

3.0 PFD EFFECTIVENESS TESTS USING HUMAN SUBJECTS

Effectiveness tests of representative types of PFDs were conducted with human subjects in calm water. The subjects were selected to represent various percentile of the population in terms of weight, since weight is strongly associated with the buoyancy requirements of the human body. Each PFD was tested on each of the performance characteristics related to PFD effectiveness, including: (a) effectiveness in turning a wearer to a position with adequate freeboard (by two tests), (b) effectiveness in maintaining a wearer in a head-back position, (c) effectiveness when the wearer adopts the heat-escape lessening posture (HELP), (d) effectiveness when held or lain upon in the water, (e) ease with which the device can be donned in the water, (f) change in position when the wearer falls into the water, and (g) time to full inflation (for inflatables).

The purpose of these tests was two-fold. First, the study provides information about the effectiveness performance of diverse types of PFDs. The study permits the comparison of representative inherently buoyant, inflatable, and hybrid devices on each of the above effectiveness performance parameters. Second, the study provides a body of effectiveness data which can be used to develop and test alternative methods for predicting PFD effectiveness parameters. The present data is used to compare the feasibility of using: (a) an anthropomorphic dummy, or (b) physical properties of the PFD (such as its center of buoyancy) to evaluate PFD effectiveness.

3.1 Method

Eleven kinds of PFDs were tested on 18 subjects. A repeated measures design was used, i.e., each type of PFD was tested on the same 18 individuals. Each subject tested two types of PFDs in each of four sessions and three PFDs in a fifth session conducted over a three day period. Session durations ranged from 45 minutes to just over one hour each. Subjects were counterbalanced by weight category (light, medium, heavy) and sex over experimental days.

The 11 kinds of PFDs tested are described in Table IV-2. For some kinds of PFDs several sizes were used to assure proper fit to all subjects. Three Type III flotation jackets, two Type III vests, and three inflatable belts were used. Inflatable belts used varied only in the size of the outer cover. All possible pairs of the 11 kinds of PFDs except the horseshoe buoy were assigned to sessions

TABLE IV-2. PFDS USED FOR EFFECTIVENESS TESTING

WYLE** NUMBER	TYPE	DESCRIPTION	FLOTATION MATERIAL	TOTAL BUOYANCY (lb)	BUOYANCY FORWARD OF BODY PROFILE CENTERLINE	USCG APPROVAL NUMBER
262	I	Kapok Vest	Kapok	32.5	24.5 (c)	160.002/78/0
* 307	III	Hybrid Vest	Unicellular PVC and CO_2 (manually actuated)	15.6 uninflated 35.4 inflated	13.8 uninflated (m) 31.1 inflated (m)	-
* 302	III	Foam Flotation Jacket (large)	Unicellular PVC	18.7	11.1 (c)	160.064/223/0
* 218	-	Modified Hybrid Vest	Unicellular PVC and air (oral inflation only)	9.5 30.1	7.5 uninflated (m) 24.5 inflated (m)	-
* 130	-	Inflatable Tube in Belt	CO_2	17.9	8.4 (c)	-
*152	-	Inflatable Yoke	CO_2	18.0	14.9 (m)	-
* 326	III	Foam Vest (large)	Unicellular PVC	15.7	10.1 (c)	160.064/162/0
345	III	Canoe-Kayak Vest	Unicellular PVC	16.3	9.4 (c)	160.064/604/0
275	-	Modified Hybrid Vest	Unicellular PVC and air (oral inflation only)	9.1 uninflated 29.7 inflated	7.8 uninflated (m) 24.7 inflated (m)	-
* 366	I	Standard Foam Yoke	Unicellular PVC	27.4	20.4 (c)	160.055/50/0
* 367	II	Standard Foam Yoke	Unicellular PVC	18.1	11.8 (c)	160.052
* 200	II	AK-1	Kapok	15.7	11.3 (c)	160.047/647/0
* 371	III	Foam Flotation Jacket (medium)	Unicellular PVC	14.9	8.8 (c)	160.064/182/0
* 370	III	Foam Flotation Jacket (small)	Unicellular PVC	13.8	9.2 (c)	160.064/181/0
* 327	III	Foam Vest (ladies small)	Unicellular PVC	15.8	10.2 (c)	160.064/247/0
* 178	IV	Cushion (15"x15"x2")	Kapok	22.8	0.0 (c)	160.048/221/0
* 292	IV	Horseshoe Buoy	Polystyrene and foam (soft)	43.0	-	160.064/075/0

NOTE:
(c) denotes calculated buoyancies forward of the centerline.
(m) denotes measured buoyancies forward of the centerline.
* designates PFDs used in the human subject tests.
** photographs of these or similar PFDs identified by Wyle number are shown in paragraph 4.0 of section III.

as nearly equally often as possible. Within this restriction and the restriction that each subject test all 11 kinds of PFDs, the assignment of pairs of PFDs to sessions was random. The horseshoe buoy was assigned to sessions such that it appeared approximately equally often with each PFD and was tested exactly once by each subject. Two complete practice sessions were conducted prior to the experiment to familiarize the experimenters with the procedure.

The subjects were 13 males and 5 females. The proportion of each sex in the sample was matched to that of boating accident victims according to ARM. Subjects were chosen so as to represent (as nearly as possible) each quintile of the distribution of American adults by weight for each sex. Subjects were paid for their participation.

Subjects were informed about the purpose of the experiment and familiarized with the procedure. They were told they could withdraw at any time. An emergency medical technician was on hand at all times while subjects were in the water. The subjects' blood pressure and pulse were taken prior to every session. Water temperature was maintained between 78° and 85°F. Air temperature varied from 85° to 95°F. The PH of the water was monitored daily and adjusted as necessary. The water was continuously filtered.

The apparatus for the experiment is described in 1.3. Additional apparatus included a chair set mounted in a metal frame used to weigh subjects both out of the water and partially submerged. During weighing, subjects were instructed to: take a deep breath, then exhale fully; during the test breathe as shallowly as possible; remain relaxed, and keep their heads level. The metal frame was connected to the load cell and block and tackle described in 1.3. The chair is shown in Figure IV-10. In weighing subjects partially submerged, the person was lowered into the water while he/she sat in the chair. The height of the chair was then adjusted until the water level was at the suprasternal notch or just touched the bottom of the chin. The subject then climbed out of the chair and the digital volt meter (DVM) was adjusted to zero and recalibrated. The subject then reentered the chair, the water level was checked, the subject was re-instructed, and his/her weight was read on the DVM. Skin-fold thicknesses were measured at four sites with a Lang skin-fold caliper. At least four readings were taken at each site for each subject. The data form is shown in Figure IV-11. Measurements were taken and tests conducted in the sequence shown on the data form. The

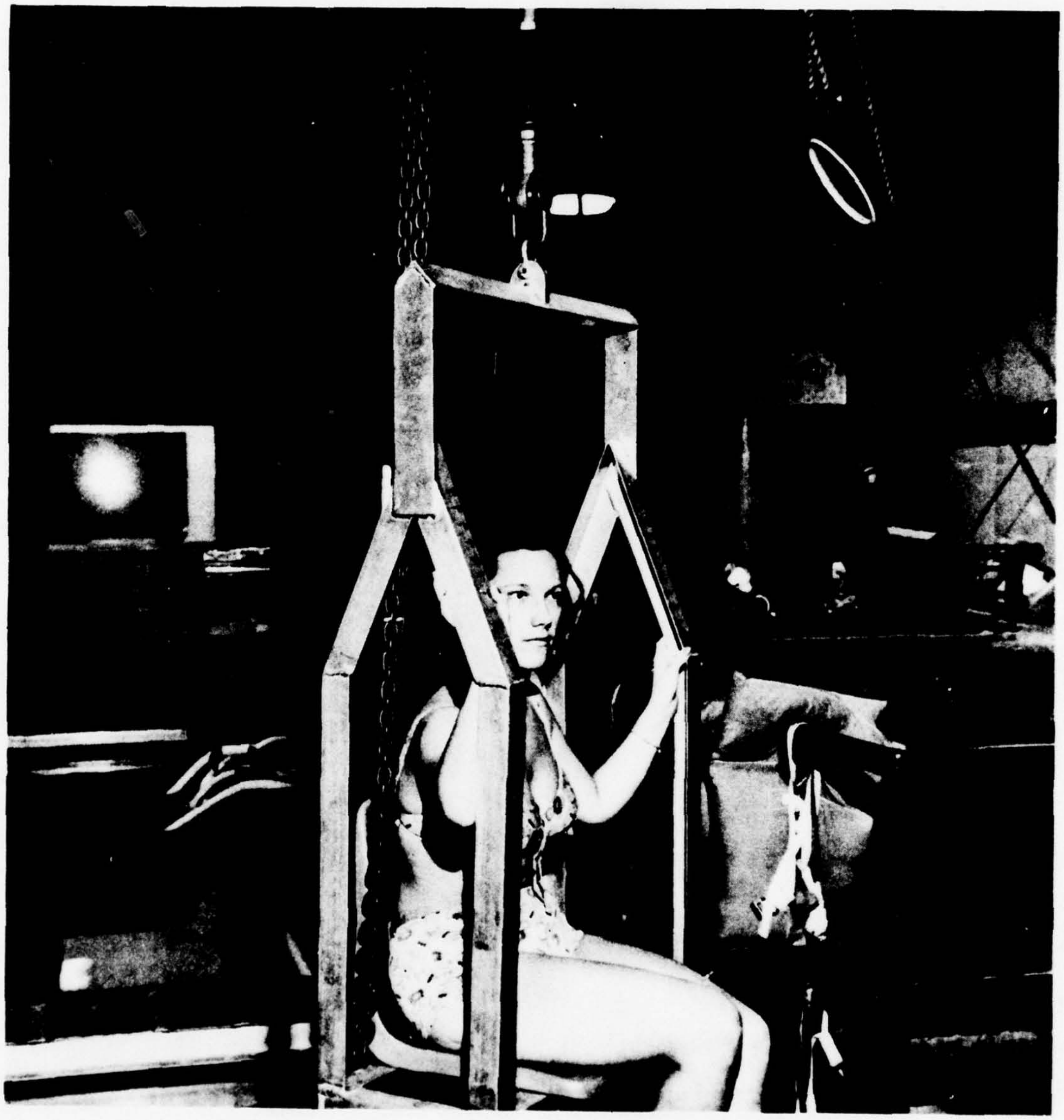


FIGURE IV-10. WEIGHING CHAIR

PFD EFFECTIVENESS EXPERIMENT - PHASE II RESEARCH

Day ____________ Session ____________ Subject no. ____________ PFD combination ________________

Date ___/___/___ Time ________ am/pm Water temperature ________ °F Air temperature ________ °F
mo day yr

Subject's name ____ Age ________ Sex ________

Hours since last meal ________ Consent form completed ________

Statements regarding health: Are you currently suffering from a cold, flu, or any other disease? ________

Do you have a history of heart disease, high blood pressure, or respiratory illness? ________

Do you know of any health-related reason why you should not participate in strenuous exercise in the water? ______

Blood pressure ________/________ Height ________ in

Circumferences: Head ________ in Wrist ________ in

Skinfold thickness: Triceps ________ mm Biceps ________ mm Subscapular ________ mm Suprailiac ________ mm

Scale weight ________ lbs (wearing swim suit only)

Weight measurements in chair (lbs):

	Body Plus Chair	Chair	Body
Total weight dry			
Submerged to suprasternal notch*			
Submerged to bottom of chin*			

*(To the subject: For this test, please take a deep breath, then exhale fully. During the test, breath as shallowly as possible, remain relaxed, and keep your head level.)

****

First PFD tested: Style ____________ (vest, collar, jacket, belt, cushion, or horseshoe)

Manufacturer ________________________ Model ____________ Type ____________ Size ____________

*The next two sections are for hybrids and inherently buoyant devices only - for inflatables, skip to "Donning PFD in the Water."

Fall Backward into Water - Part I: Uninflated (Run at least one practice fall without inflation prior to taking data. For inflatable PFDs, go directly to Part II (after practice).)

(To the subject: Stand at the end of the pool and allow yourself to fall backward into the water. Be careful to fall straight back so you do not hit the side of the pool. Do not actuate or inflate the PFD. Once you come to the surface, please relax and allow the PFD to turn you to whatever position it takes you. Before you start, take a deep breath and exhale fully. Breathe as shallowly as possible.)

Photo # (above water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

1

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

Rate whether the PFD changed position on the subject's body (circle one number each):

Experimenter I _____

1	2	3	4
Rode over head or changed position radically	Rode up moderately to chin or armpits	Rode up or changed slightly	No change
1	2	3	4

Experimenter II _____

Buoyancy and Orientation Wearing PFD (Uninflated) (Run at least one practice trial in each position before taking data.)

1. Head down, arms extended laterally, forward leaning position.

Photo # (above water) of final position _________ Photo # (below water) of final position _________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

2. Head back, arms extended laterally, backward leaning.

Photo # (above water) of final position _________ Photo # (below water) of final position _________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

3. HELP position.

Photo # (above water) of final position _________ Photo # (below water) of final position _________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

2

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS, Continued

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

Donning PFD in the Water (Have the subject practice donning the PFD out of the water before this test.)

(To the subject: Please enter the deep end of the tank. You will be given a PFD to put on in the water. Please inflate the PFD, if possible, and don it as quickly as possible after I give it to you. Stay in the middle of the tank and do not touch the walls. Be sure to adjust all straps and fasten all snaps, buckles, etc. You will be timed from when you first get the PFD until it is completely donned.)

Time _____________ secs

Rate the degree of difficulty experienced by the subject (circle one number each):

	1	2	3	4
Experimenter I ____(initials)	1	2	3	4
	serious difficulty	moderate difficulty	slight difficulty	no difficulty
Experimenter II ____(initials)	1	2	3	4
	required assistance; probably would not have been successful in rough water; had serious trouble staying afloat	some trouble keeping head out of water; trouble with fasteners or straps		

Fall Backward into Water - Inflated (Run at least one practice fall without inflation prior to taking data.)

(To the subject: Stand at the end of the pool and allow yourself to fall backward into the water. Be careful to fall straight back so you do not hit the side of the pool. Once you come to the surface, please relax and allow the PFD to turn you to whatever position it takes you. Before you start, take a deep breath and exhale fully. Breathe as shallowly as possible.)

Time ________ secs to full inflation. Note any difficulties or malfunction in inflation: ______________________

____

____

Photo # (above water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

Rate whether the PFD changed position on the subject's body (circle one number each):

Experimenter I _____	1	2	3	4
	Rode over head or changed position radically	Rode up moderately to chin or armpits	Rode up or changed slightly	No change
Experimenter II _____	1	2	3	4

3

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS, Continued

Buoyancy and Orientation Wearing PFD (Inflated)

(To the subject: Please adopt each of several positions which I'll describe to you and then let yourself go limp. Before you start each position, take a deep breath and exhale fully. During the test, hold your breath or breathe as shallowly as possible and remain relaxed. After I tell you to go limp, please do not try to control your position in the water. Just let yourself turn to whatever position the PFD takes you.

1. Head down, arms extended laterally, forward leaning position.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

2. Head back, arms extended laterally, backward leaning.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

3. HELP position.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

****

4

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS, Continued

Second PFD tested: Style ________________(vest, collar, jacket, belt, cushion, or horseshoe)

Manufacturer ______________________________ Model ____________ Type ____________ Size ____________

*The next two sections are for hybrids and inherently buoyant devices only - for inflatables, skip to "Donning PFD in the Water."

Fall Backward into Water - Part I: Uninflated (Run at least one practice fall without inflation prior to taking data.)

(To the subject: Stand at the end of the pool and allow yourself to fall backward into the water. Be careful to fall straight back so you do not hit the side of the pool. Do not actuate or inflate the PFD. Once you come to the surface, please relax and allow the PFD to turn you to whatever position it takes you. Before you start, take a deep breath and exhale fully. Breathe as shallowly as possible.)

Photo # (above water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

Rate whether the PFD changed position on the subject's body (circle one number each):

Experimenter I _____

1	2	3	4
Rode over head or changed position radically	Rode up moderately to chin or armpits	Rode up or changed slightly	No change
1	2	3	4

Experimenter II _____

Buoyancy and Orientation Wearing PFD (Uninflated) (Run at least one practice trial in each position before taking data.)

1. Head down, arms extended laterally, forward leaning position.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

5

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS, Continued

2. Head back, arms extended laterally, backward leaning.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

3. HELP position.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

Donning PFD in the Water (Have the subject practice donning the PFD out of the water before this test.)

(To the subject: Please enter the deep end of the tank. You will be given a PFD to put on in the water. Please inflate the PFD, if possible, and don it as quickly as possible after I give it to you. Stay in the middle of the tank and do not touch the walls. Be sure to adjust all straps and fasten all snaps, buckles, etc. You will be timed from when you first get the PFD until it is completely donned.)

Time ____________ secs

Rate the degree of difficulty experienced by the subject (circle one number each):

	1	2	3	4
Experimenter I _____(initials)	1	2	3	4
	serious difficulty	moderate difficulty	slight difficulty	no difficulty
Experimenter II _____(initials)	1	2	3	4
	required assistance; probably would not have been successful in rough water; had serious trouble staying afloat	some trouble keeping head out of water; trouble with fasteners or straps		

6

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS, Continued

Fall Backward into Water - Inflated (Run at least one practice fall without inflation prior to taking data.)

(To the subject: Stand at the end of the pool and allow yourself to fall backward into the water. Be careful to fall straight back so you do not hit the side of the pool. Once you come to the surface, please relax and allow the PFD to turn you to whatever position it takes you. Before you start, take a deep breath and exhale fully. Breathe as shallowly as possible.)

Time ________ secs to full inflation. Note any difficulties or malfunction in inflation: ____________________

____

____

Photo # (above water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

Rate whether the PFD changed position on the subject's body (circle one number each):

Experimenter I _____

1	2	3	4
Rode over head or changed position radically	Rode up moderately to chin or armpits	Rode up or changed slightly	No change
1	2	3	4

Experimenter II _____

Buoyancy and Orientation Wearing PFD (Inflated)

(To the subject: Please adopt each of several positions which I'll describe to you and then let yourself go limp. Before you start each position, take a deep breath and exhale fully. During the test, hold your breath or breathe as shallowly as possible and remain relaxed. After I tell you to go limp, please do not try to control your position in the water. Just let yourself turn to whatever position the PFD takes you.

1. Head down, arms extended laterally, forward leaning position.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II _____

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I _____

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II _____

2. Head back, arms extended laterally, backward leaning.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

7

FIGURE IV-11. DATA FORM FOR HUMAN SUBJECT TESTS, Continued

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I ______

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II ______

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I ______

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II ______

3. HELP position.

Photo # (above water) of final position ________ Photo # (below water) of final position ________

Rate the subject's final equilibrium angle by placing an "X" at the appropriate spot along the following scale:

Experimenter I ______

Head fully forward - face submerged	Head 45° forward	Head vertical (erect)	Head 45° back	Head fully back - horizontal

Experimenter II ______

Estimate the freeboard of the subject's lower respiratory passage in the final resting position by placing an "X" at the appropriate spot along the following scale:

Experimenter I ______

Passage submerged	Near waterline	Moderate - about 1"	Well clear - 3" or more

Experimenter II ______

****

Holding/Laying on PFD (Run hybrids inflated)

(To the subject: Find the position in which the PFD can be held with the least effort. The experimenter will suggest several positions and you may also try your own. For each PFD, decide which position would be easiest if you had to support yourself while stranded in the ocean for hours.)

PFD number and description ________________________________

Easiest position - describe ________________________________

Photo # ____________ Rank ____________

PFD number and description ________________________________

Easiest position - describe ________________________________

Photo # ____________ Rank ____________

PFD number and description ________________________________

Easiest position - describe ________________________________

Photo # ____________ Rank ____________

Now rank the PFDs according to which is easier to hold on to or lay on in its most preferred position (1 = easiest).

Position code:
1. PFD around back of neck and over chest, held down by laying arms over chest.
2. Ends of PFD under armpits, middle of PFD under subject's chin.
3. Subject floating on back, PFD held to chest.
4. Vest or jacket PFD donned but not fastened.
5. Vest or jacket PFD donned backward.
6. Subject floating on stomach, PFD under chest folded.
7. Subject floating on stomach, PFD under chest open.
8. PFD on chest, arms through straps.

horseshoe buoy was used only in the last test. On the last test the subject compared all the PFDs tested in that session for ease of holding or laying upon in the water.

In the test that involved donning PFDs in the water, subjects were instructed to first inflate and then don the inflatable yoke and the inflatable belt. The hybrid devices were first donned and then inflated. Timing commenced when the PFD hit the water directly in front of the subject (who was treading water) and terminated when the PFD was fully donned and fastened. The inflatable belt was donned by first fastening the buckle, then placing the circular tube around the chest and under the arms. The cushion was donned by placing one strap around the subject's neck and the other around one leg at the thigh. In the fall test, the subject stood at the edge of the pool (6 in. above water level) with his back toward the water. The subject was instructed to fall backward into the water, simulating a fall overboard from a recreational boat. In this test the subject's torso was nearly horizontal when he hit the water. A test in which the subject bends his knees as he falls backward, or steps forward into the water would result in his hitting the water with his torso more nearly vertical. Such a test would probably produce greater displacement of the PFD. The subject was instructed to manually actuate the CO_2 equipped devices immediately after hitting the water, and the modified hybrid vest immediately after surfacing. In the fall test the subject was shown how to actuate the PFD but was instructed not to put his hand on the actuator until after he had entered the water. Inflation times in this test therefore include the time required by the subject to locate the actuator mechanism. Timing was started when the subject first touched the water surface.

Experience showed that the subject's degree of relaxation could be judged by the position of his head. Subjects seemed to be most conscious of tenseness in their limbs and shoulders and generally had no trouble relaxing these parts of the body. The neck was generally the last part relaxed, judging from the appearance of the subject in the water. Full relaxation of the neck can, of course, be judged by the position of the head. If the subject allows his head to fall forward or back in the natural resting position (not as extreme as a forced forward or back position), one can be reasonably confident that he is fully relaxed. Tests were repreated as necessary at the experimenter's discretion to assure that subjects were fully relaxed.

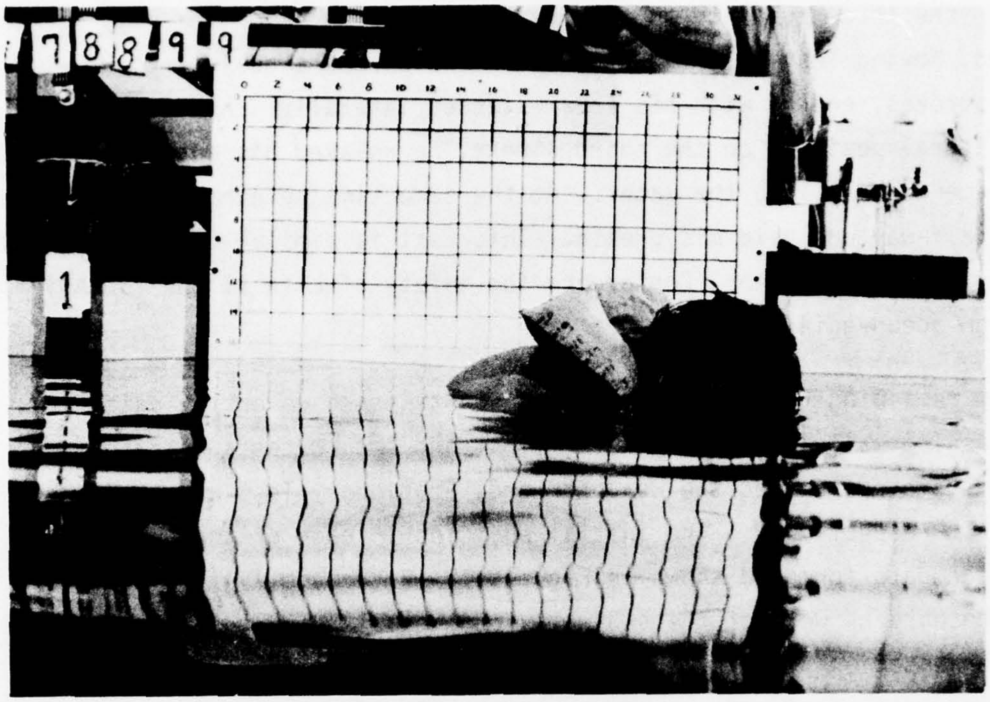
In addition to the three buoyancy and orientation tests shown on the data form, a Head Forward, Moving Test was conducted. In this test the subject took 2-1/2 gentle breaststrokes, ending with his arms extended laterally. As his arms reached the lateral position on the third stroke, he relaxed his entire body and allowed his face to fall into the water. At the same time he exhaled to what he judged to be half-way and held his breath. This test is similar to the test recommended by the International Conference for Safety of Life at Sea (SOLAS) for life jackets on ocean-going vessels.

In each of the remaining buoyancy and orientation tests shown on the data form, the subject was initially stationary. The first and second tests described on the forms are therefore called the Head Forward, Stationary Test and Head Back, Stationary Test, respectively. The initial position in each of these tests is described on the data form and shown in Figures IV-12 through IV-14. Above and below water photographs were of the subjects final equilibrium position in each buoyancy and orientation test, except for the moving test. Due to the difficulty of properly positioning the subject, the results for the moving test are based on experimenter estimates. Up to 20 seconds were allowed for the PFD to turn the subject in all tests (SOLAS requires that the mouth be clear of the water in not more than 5 seconds).

In the test entitled, "Holding/Laying on PFD," the subject found the best (defined as requiring least effort) position to hold or lay on the PFD without fully donning it. The subject then ranked the two or three PFDs used in that session from easiest to hardest to hold or lay upon in the water.

3.2 Results

Characteristics of the subjects are shown in Table IV-3. Skeletal size was estimated from wrist circumference. Body density was based on average skin-fold thicknesses at several sites. The proportion of tests in which the PFDs turned each subject are shown in the right-hand column of Table IV-3. These results were correlated with various subject characteristics to determine which body measurements were associated with ease of turning. The results are shown in Table IV-4. None of the characteristics showed a significant linear relationship with ease of turning for the present small sample. The present sample



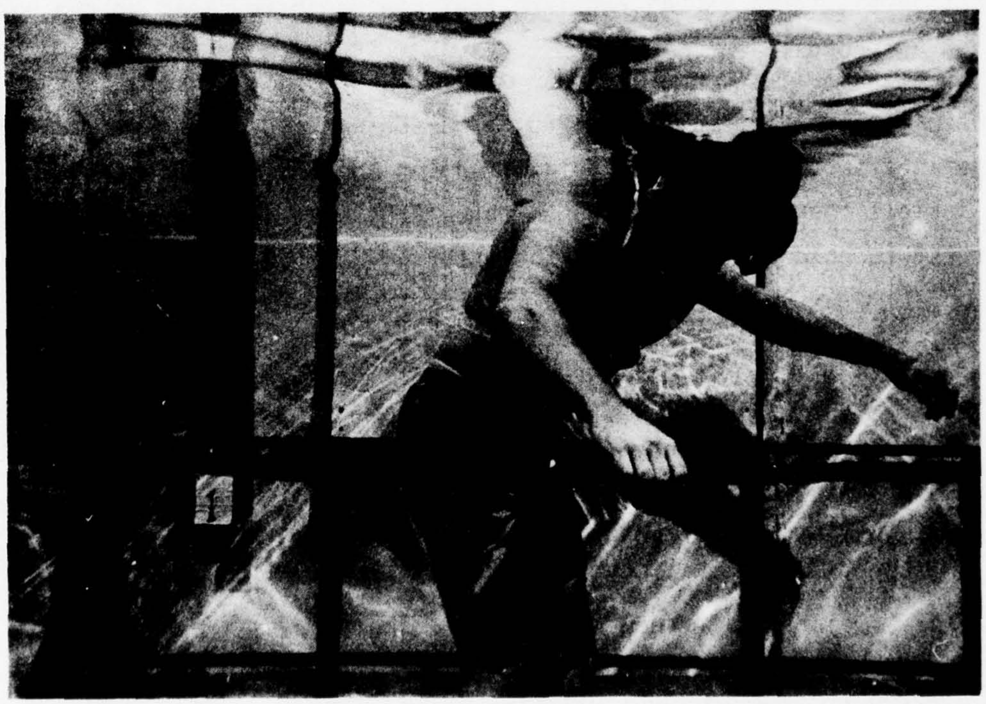
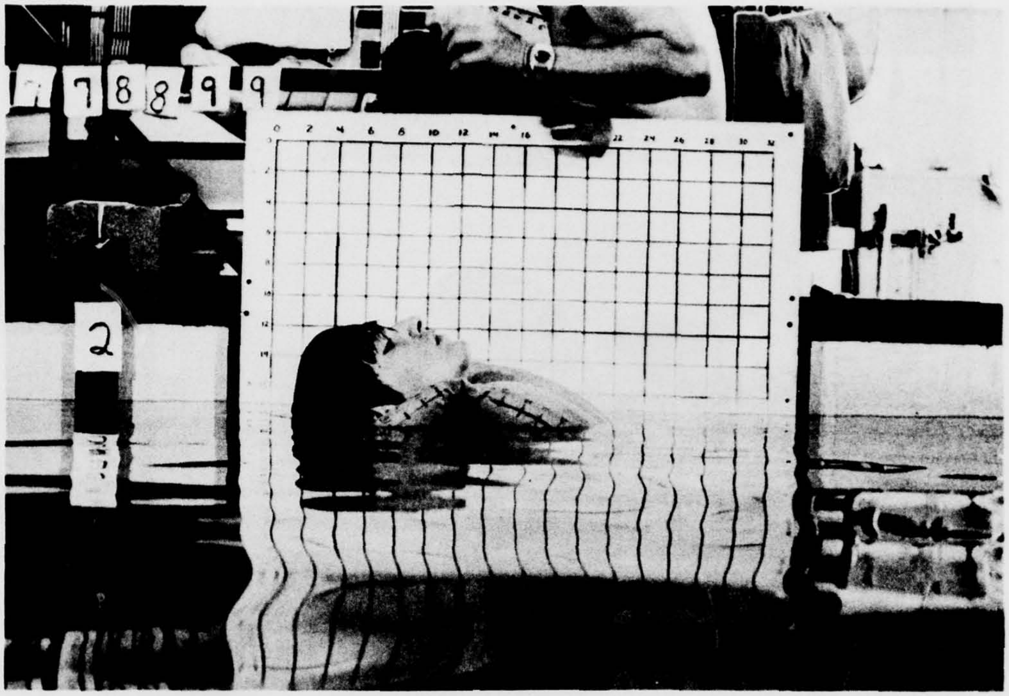


FIGURE IV-12. HEAD FORWARD STATIONARY TEST



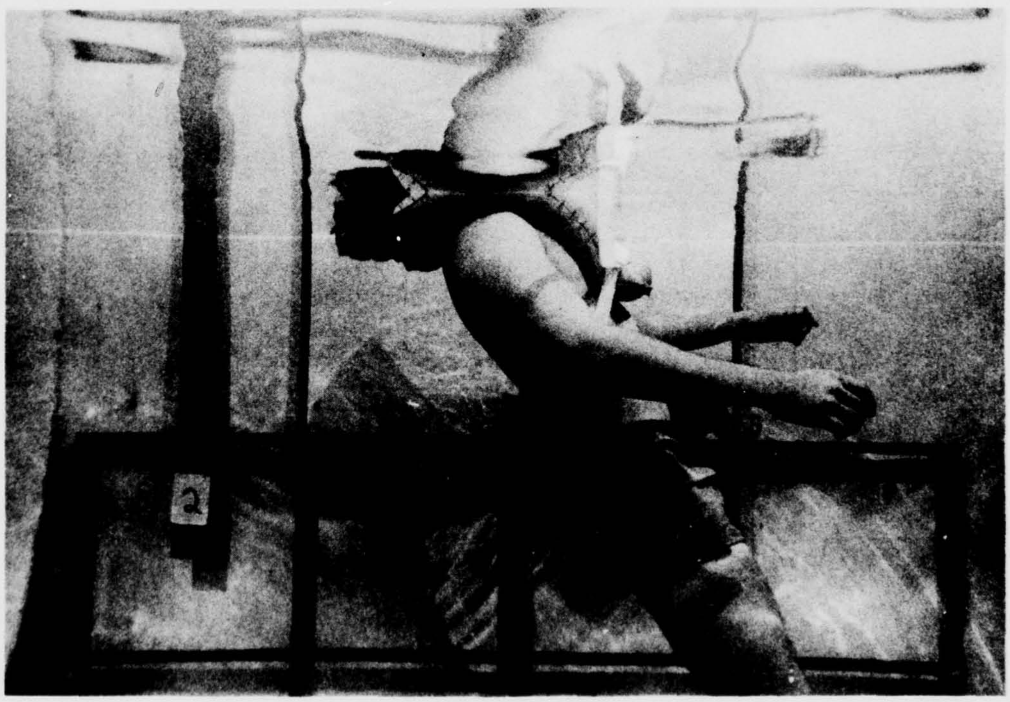
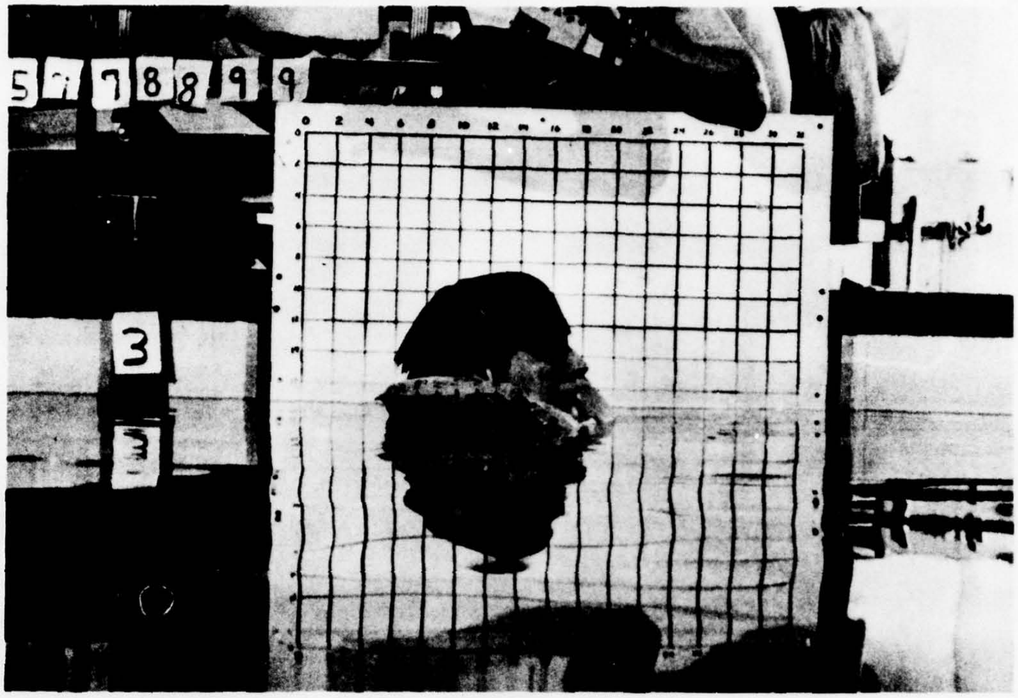


FIGURE IV-13. HEAD BACK STATIONARY TEST



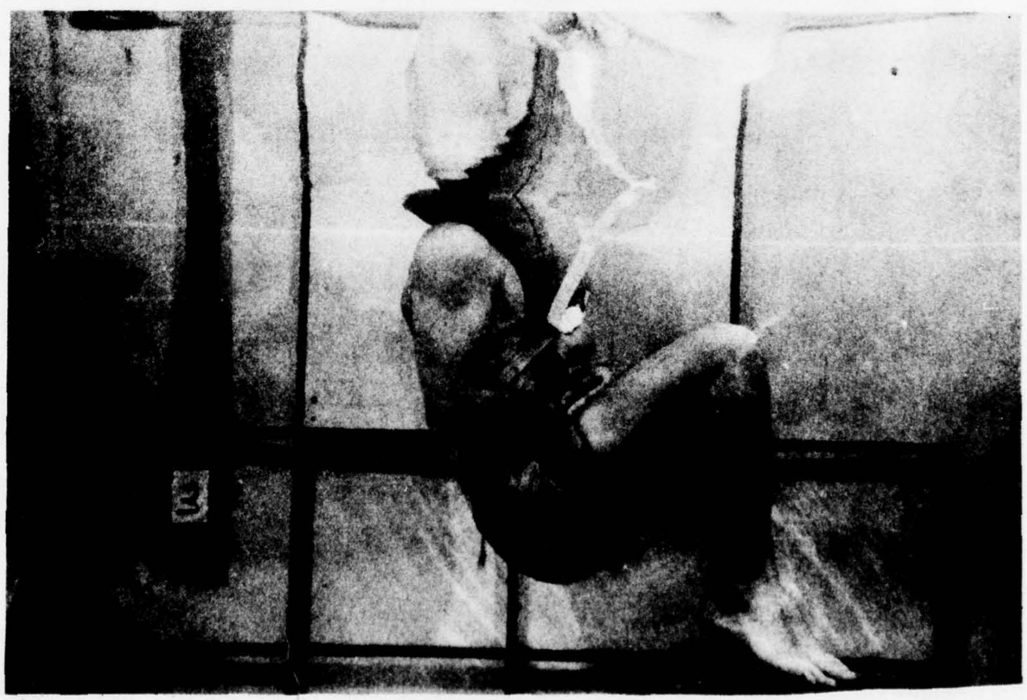


FIGURE IV-14. HEAT ESCAPE LESSENINC

SUBJECT NUMBER	SEX	AGE (years)	HEIGHT (inches)	HEAD CIRCUM-FERENCE (inches)	WRIST CIRCUM-FERENCE (inches)	EST. SKELETAL SIZE*	AVERAGE SKIN-FOLD THICKNESSES (mm)					D (
							TRICEPS	BICEPS	SUB-SCAPULAR	SUPRA-ILIAC	MEAN	
4	M	20	70.5	22.0	6.5	LF	17.2	7.0	11.8	12.6	12.2	1
3	M	29	71.6	22.9	6.9	LF	19.5	12.3	13.0	14.4	14.8	1
6	M	32	69.4	22.0	7.1	LF	20.5	9.4	11.5	23.8	16.3	1
9	M	23	72.1	22.4	6.8	LF	17.3	9.3	13.5	18.3	14.6	1.
8	M	21	68.4	23.0	7.1	LF	20.0	10.4	15.4	19.8	16.4	1.
7	M	21	66.9	22.8	6.9	LF	19.0	14.5	28.6	22.4	19.6	1.
11	M	31	73.4	23.3	7.3	LF	14.8	10.0	14.4	21.8	15.2	1.
10	M	25	72.5	23.6	7.3	LF	25.4	15.0	18.8	29.8	22.2	1.
12	M	20	75.5	23.8	7.5	LF	16.4	9.0	14.2	23.6	15.8	1.
14	M	26	68.0	23.6	7.9	LF	23.5	16.0	30.8	29.8	25.0	1.
13	M	30	67.7	22.7	8.1	LF	36.0	20.0	34.8	27.6	29.6	1.
16	M	30	78.5	22.8	7.4	LF	21.5	10.6	18.4	27.5	19.5	1.
18	M	18	71.0	24.0	9.2	LF	23.6	14.0	19.0	28.6	21.3	1.
19	F	33	64.8	22.4	5.2	SF	15.0	9.6	10.4	14.0	12.3	1.
20	F	34	65.8	22.1	5.6	SF	19.2	5.2	15.0	18.8	14.6	1.
21	F	23	66.5	23.0	6.4	MF	24.5	17.0	17.3	22.0	20.2	1.
23	F	40	65.0	21.9	6.8	LF	21.8	16.6	26.6	24.4	22.4	1.
22	F	24	69.3	21.5	6.5	LF	29.2	15.8	21.2	23.4	22.4	1.

[1]"Weight, Height, and Selected Body Dimensions of Adults." National Center for Health Statistics, U.S Education, and Welfare, June 1965.

* LF = Large Frame, MF = Medium Frame, SF = Small Frame

[2] Lander, P. & Lander, D. How to Assess Degrees of Fatness: A Working Manual, 1973

...CKNESSES (mm)		EST. DENSITY (gm/cc)[2]	WEIGHT (lb)		BUOYANCY REQUIREMENTS (lb)		PERCENTILE WEIGHT BY NCHS DATA[1]	PROPORTION OF PFDS IN WHICH SUBJECT WAS TURNED TO VERTICAL OR BACKWARD-LEANING POSITION IN THE WATER	
SUPRA-ILIAC	MEAN		SCALE	LOAD CELL	SUPRA-STERNAL NOTCH	BOTTOM OF CHIN		STATIONARY TEST	MOVING TEST
12.6	12.2	1.0545	143.9	143.4	18.2	14.1	19	0.17	0.42
14.4	14.8	1.0486	153.3	152.5	22.6	15.0	31	0.17	-
23.8	16.3	1.0464	165.1	164.4	18.1	11.3	48	0.00	0.67
18.3	14.6	1.0494	172.0	170.9	18.4	13.8	57	0.25	0.17
19.8	16.4	1.0462	172.0	171.9	23.5	15.0	58	0.17	0.50
22.4	19.6	1.0412	178.5	177.0	17.3	10.7	65	0.33	0.67
21.8	15.2	1.0482	196.3	196.7	17.6	12.3	85	0.33	0.50
29.8	22.2	1.0378	204.8	204.4	24.4	15.4	90	0.17	-
23.6	15.8	1.0472	205.0	204.9	21.3	15.2	90	0.42	0.42
29.8	25.0	1.0346	208.0	208.2	22.5	16.0	92	0.33	0.50
27.6	29.6	1.0299	216.6	216.6	21.5	12.6	95	0.25	0.75
27.5	19.5	1.0413	228.0	227.8	24.2	16.4	98	0.17	0.25
28.6	21.3	1.0390	230.3	230.2	26.9	19.8	98	0.33	0.42
14.0	12.3	1.0365	98.8	98.8	12.3	9.1	2	0.33	0.08
18.8	14.6	1.0311	122.0	121.4	11.3	8.2	25	0.17	-
22.0	20.2	1.0208	133.5	133.2	13.6	10.6	44	0.17	0.17
24.4	22.4	1.0176	168.2	167.5	12.6	6.7	82	0.42	0.75
23.4	22.4	1.0176	172.1	171.7	12.9	9.5	85	0.0	0.08

...th Statistics, U.S. Department of Health,

...73

TABLE IV-3. SUBJECT CHARACTERISTICS

TABLE IV-4. PRODUCT MOMENT CORRELATIONS OF BODILY CHARACTERISTICS WITH EASE OF TURNING FOR MALE SUBJECTS

BODY MEASUREMENT	PROPORTION OF PFD CONFIGURATIONS IN WHICH SUBJECT WAS TURNED	
	STATIONARY TEST	MOVING TEST
Weight (by Load Cell)	+0.45	-0.07
Additional Buoyancy Required to Support the Subject Above the Suprasternal Notch (SSN)	+0.05	-0.22
Additional Buoyancy Required to Support the Subject Above the Bottom of the Chin	+0.22	-0.53
Estimated Body Density	-0.23	+0.36

NOTE: None of the coefficients was significant ($p < 0.05$).

should be augmented to determine which body characteristics influence ease of turning. This information would be helpful in designing dummies for use in evaluating PFDs.

Table IV-5 shows the results of the test in which the subject fell backward into the water. Of the CO_2 equipped devices, the time to inflation was longest for the inflatable belt, due to the fact that it uses a squeeze-type actuator contained inside the inflatable chamber. In informal testing of this particular inflatable belt, several instances have been noted when the wearer experienced considerable difficulty in finding and operating the actuator. A maximum time-to-inflation test, based on a fall into the water by a subject unfamiliar with the PFD, should be part of the effectiveness test sequence. Table IV-5 also shows the median position-change (security of fit) ratings for each PFD. None of the PFDs tested had a position change rating of less than 2 in this study. A rating of 1 should be considered a failure. The inflatable belt should (and generall did) ride up to a position under the armpits for maximum effectiveness.

Above-water photographs of each subject's equilibrium position in the buoyancy and orientation tests were enlarged and used to measure freeboard to the subject's lower respiratory passage. Below-water photographs were used to measure the subject's equilibrium angle. Equilibrium angle was measured by locating points in the photograph corresponding to the middle of the subject's shoulder and hip. A line was then drawn connecting these points. A second vertical line was drawn using the grid background. A protractor was used to measure the inclination of the line drawn through the hip and shoulder points to the vertical.

Tables IV-6 and IV-7 and Figures IV-15 through IV-17 show measures of effectiveness of the PFDs for each of the buoyancy and orientation tests. A PFD was considered to have turned the subject if the equilibrium angle was less than or equal to zero (subject backward leaning or vertical). The effectiveness of the device in providing 4 in. or more freeboard is also tabulated.*

---

* The SOLAS requirement is that the mouth be clear of the water by at least 12 cm (4.72 in.) with the trunk floating inclined backwards at an angle of not less than 20° and preferrably not more than 50° from vertical.

TABLE IV-5. MEAN TIME FROM INITIAL CONTACT WITH WATER TO FULL INFLATION AND MEDIAN POSITION CHANGE RATING FOR THE FALL INTO THE WATER TEST

PFD	MEAN TIME TO FULL INFLATION (SECONDS)	MEDIAN POSITION CHANGE RATING
Type I Standard Foam Yoke (366)	—	3.08
Type III Hybrid Vest Inflated (307)	3.59	3.44
Modified Hybrid Vest Inflated (218)	30.5 (oral inflation)	3.33
Inflatable Yoke (152)	5.11	3.40
Type II Standard Foam Yoke (367)	—	3.77
Type II AK-1 (200)	—	3.77
Type IV Cushion (178)	—	3.28
Modified Hybrid Vest Uninflated (218)	—	3.06
Type III Hybrid Vest Uninflated (307)	—	3.22
Type III Foam Vest (326, 327)	—	3.82
Type III Foam Flotation Jacket (302, 370, 371)	—	3.10
Inflatable Tube In Belt (130)	7.78	2.10

Rating Scale for Position Change:

1	2	3	4
Rode over head or changed position radically	Rode up moderately to chin or armpits	Rode up or changed slightly	No Change

TABLE IV-6. TURNING EFFECTIVENESS AND EFFECTIVENESS WHEN WORN

PFD	TEST: HEAD FORWARD STATIONARY N=18		TEST: HEAD FORWARD MOVING N=15	
	E_T [a]	E_W [b]	E_T	E_W
Type I Standard Foam Yoke (366)	0.83	0.72	0.93	0.87
Type III Hybrid Vest Inflated (307)	0.39	0.39	0.80	0.80
Modified Hybrid Vest Inflated (218)	0.61	0.56	0.73 (0.75)*	0.73 (0.50)
Inflatable Yoke (152)	0.44	0.22	0.67	0.67
Type II Standard Foam Yoke (367)	0.28	0.22	0.60	0.60
Type II AK-1 (200)	0.06	0	0.53 (0.80)	0.40 (0.15)
Type IV Cushion (178)	0.78	0.17	0.60	0.20
Modified Hybrid Vest Uninflated (218)	0	0	0.33 (0.50)	0.13 (0.15)
Type III Hybrid Vest Uninflated (307)	0	0	0.27	0.20
Type III Foam Vest (326, 327)	0	0	0.07	0.07
Type III Foam Flotation Jacket (302, 370, 371)	0	0	0	0
Inflatable Tube In Belt (130)	0	0	0	0

[a] E_T = proportion of subjects turned to vertical or backward leaning position

[b] E_W = proportion of subjects for whom the PFD provided $\geq$ 4 in. freeboard to the lower respiratory passage in the final equilibrium position.

* Figures in parentheses are based upon results reported by Underwriters Laboratories, Inc., for same PFDs in same test (with 4 in. freeboard requirement in E_W and maximum 20 seconds turn time in both E_T and E_W).

TABLE IV-7. PROPORTION OF SUBJECTS MAINTAINED IN A POSITION WITH AT LEAST 4 IN. FREEBOARD TO LOWER RESPIRATORY PASSAGE

PFD	TEST	
	HEAD BACK STATIONARY (E_{W_C})	HELP POSITION
Type I Standard Foam Yoke (366)	0.94	0.89
Type III Hybrid Vest Inflated (307)	0.94	0.56
Modified Hybrid Vest Inflated (218)	1.00	0.67
Inflatable Yoke (152)	0.78	0.22
Type II Standard Foam Yoke (367)	1.00	0.50
Type II AK-1 (200)	0.94	0.33
Type IV Cushion (178)	0.50	0.39
Modified Hybrid Vest Uninflated (218)	0.56	0.11
Type III Hybrid Vest Uninflated (307)	0.83	0.17
Type III Foam Vest (326, 327)	0.94	0.17
Type III Foam Flotation Jacket (302, 370, 371)	0.94	0.11
Inflatable Tube In Belt (130)	1.00	0.11

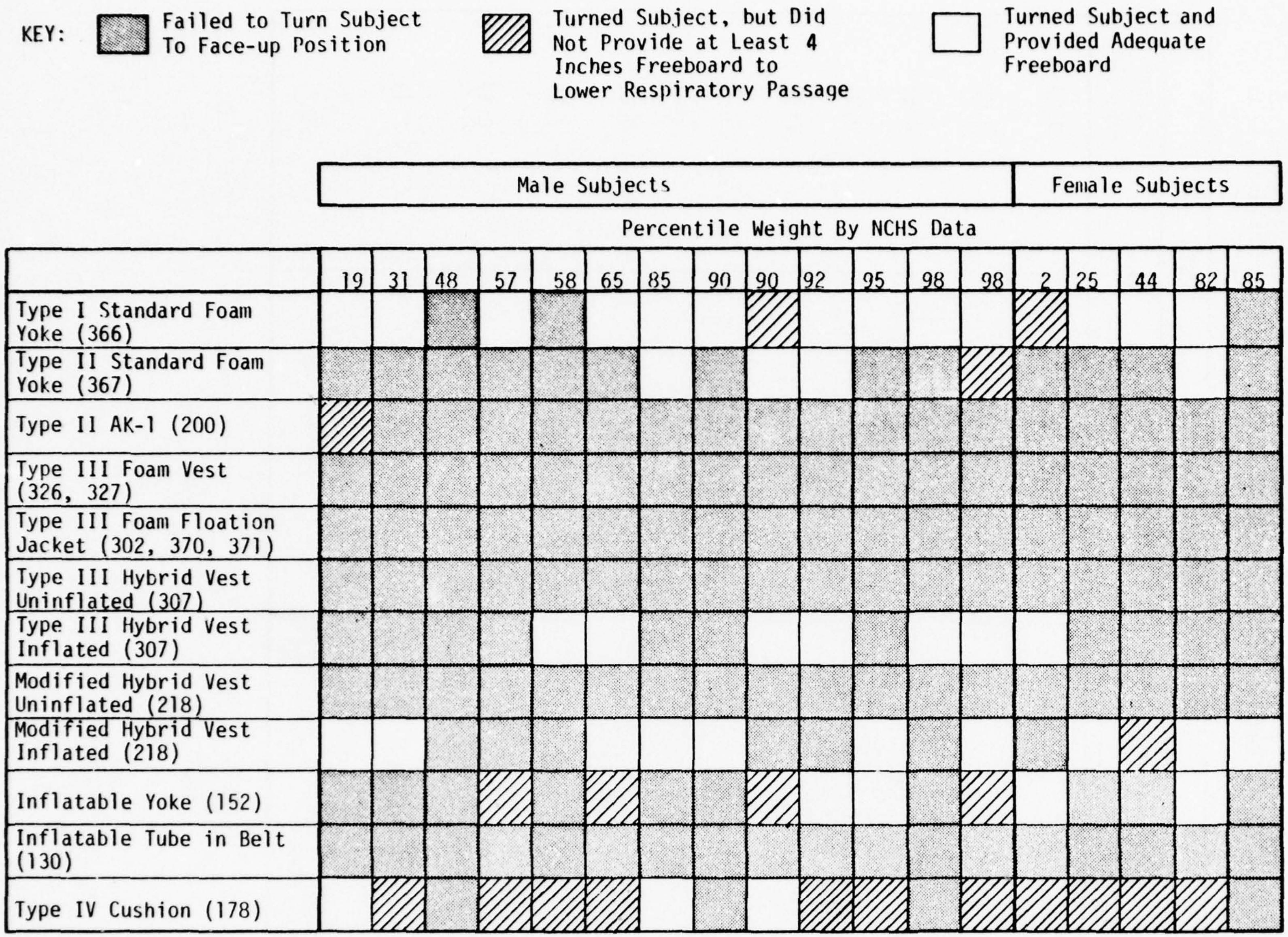


FIGURE IV-15. EFFECTIVENESS PERFORMANCE OF SELECTED PFDS - HEAD FORWARD, STATIONARY TEST

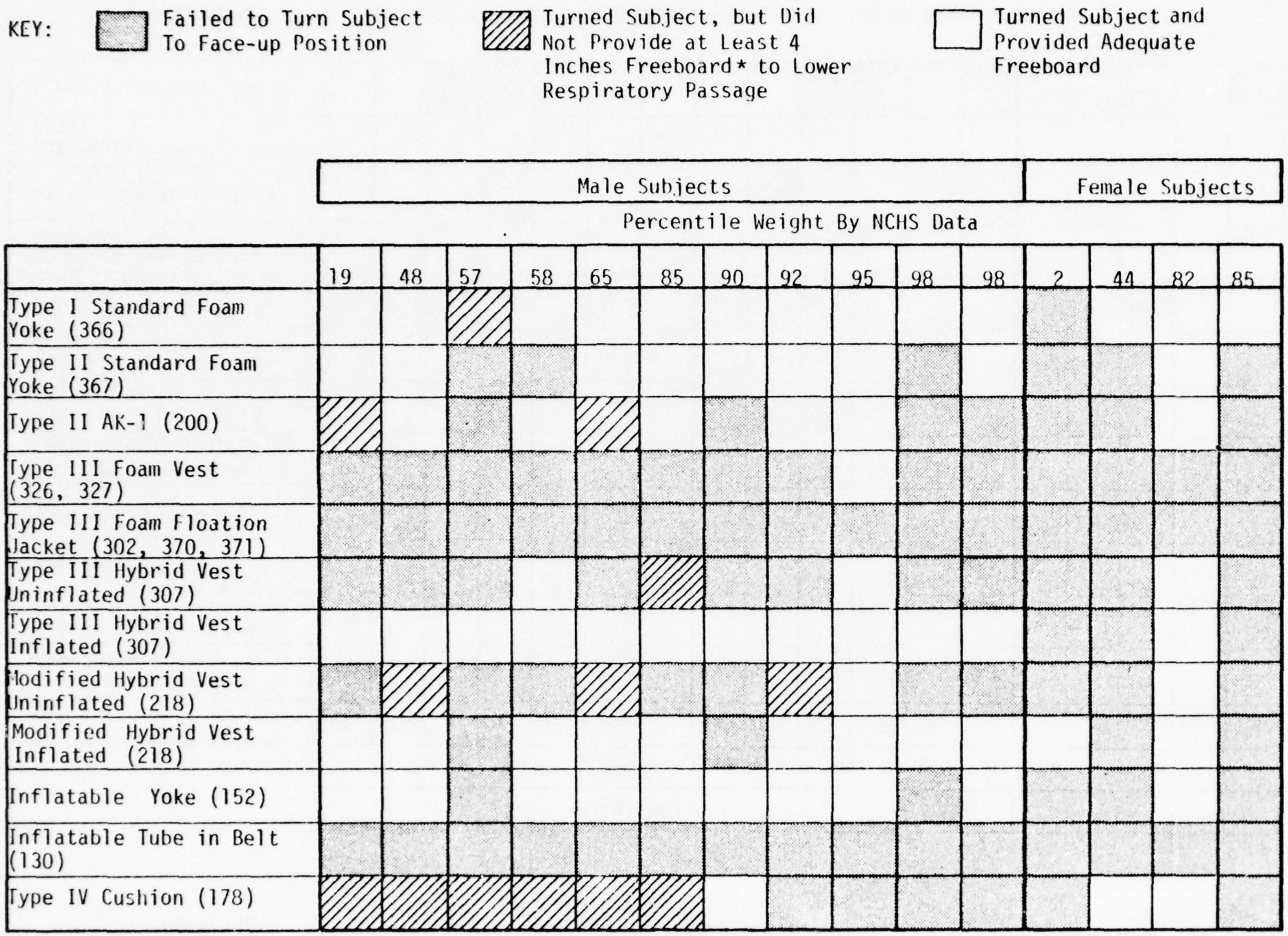


FIGURE IV-16. EFFECTIVENESS PERFORMANCE OF SELECTED PFDS - HEAD FORWARD, MOVING TEST

* Experimenter estimate

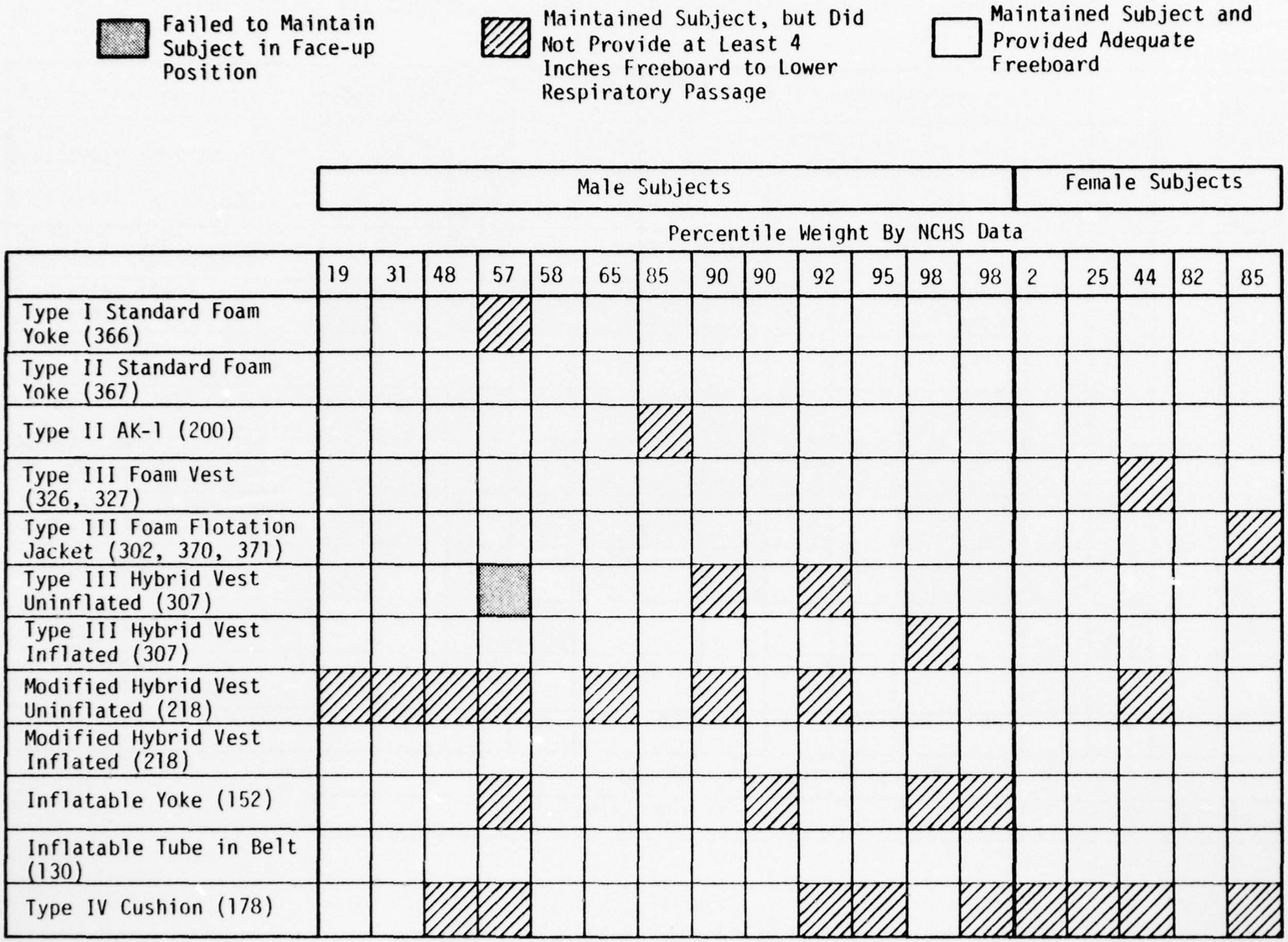


FIGURE IV-17. EFFECTIVENESS PERFORMANCE OF SELECTED PFDS - HEAD BACK, STATIONARY TEST

The average time required to don each PFD in the water and median donning difficulty ratings are shown in Table IV-8. Table IV-8 also shows the proportion of subjects who experienced various degrees of difficulty in donning each PFD. Recreational boating accident victims would be expected to experience much greater difficulty than subjects in this experiment, where conditions were ideal. The proportion of subjects who experience no difficulty in the present study is therefore used to estimate the probability of donning in the LSI equation (see Paragraph 3.3).

The ease with which the PFDs can be held or lain upon in the water is summarized in Table IV-9. These scores were computed by summing the proportion of times each PFD was ranked above each of the other PFDs. These scores are used as estimates of the effectiveness of the PFD when held (E_H) in the LSI. Some of the positions for holding or laying upon PFDs used by subjects in this experiment are shown in Figure IV-18.

TABLE IV-8. PROBABILITY THAT A BOATING ACCIDENT VICTIM SUCCESSFULLY DONS SPECIFIED PFDS IN THE WATER GIVEN THAT THE PFD IS ACCESSIBLE AND NOT DISCARDED (ESTIMATED FROM DONNING DIFFICULTY EVALUATIONS), AND MEAN TIME REQUIRED TO DON THE PFD IN THE WATER

PFD	PROPORTION OF SUBJECTS WHO EXPERIENCED:				
	NO DIFFICULTY[1]	NO OR SLIGHT DIFFICULTY[1]	NO, SLIGHT, OR MODERATE DIFFICULTY[1]	MEAN DONNING TIME (SEC.)	MEDIAN DIFFICULTY RATING
Type I Standard Foam Yoke* (366)	0.94	1.0	1.0	24.9	3.97
Type II Standard Foam Yoke* (367)	0.83	1.0	1.0	32.3	3.90
Type II AK-1 (200)	0.82	1.0	1.0	35.3	3.89
Type III Foam Vest* (326, 327)	0.71	0.88	0.94	37.4	3.79
Type III Foam Flotation Jacket* (302, 370, 371)	0.41	0.82	1.0	50.6	3.28
Type III Hybrid Vest Inflated (307)	0.44	0.63	1.0	47.6	3.17
Modified Hybrid Vest Inflated (218)	0.47	0.59	0.94	89.0	3.25
Inflatable Yoke* (152)	0.22	0.67	0.94	48.8	2.88
Inflatable Tube In Belt (130	0.82	1.0	1.0	28.9	3.89
Type IV Cushion (178)	0.94	1.0	1.0	10.5	3.97

[1] Rating scale for donning difficulty:

1	2	3	4
serious difficulty	moderate difficulty	slight difficulty	no difficulty
1	2	3	4
required assistance; probably would not have been successful in rough water; had serious trouble staying afloat			

* Denotes reference PFDs for use in the effectiveness test procedure (see Paragraph 7.2).

TABLE IV-9. PFD RANKINGS BY THE EASE WITH WHICH THEY CAN BE HELD OR LAIN UPON IN THE WATER (THE HIGHER THE SCORE, THE EASIER)

	Modified Hybrid Vest Inflated (218)	0.825
0.80		
	Type II AK-1 (200)	0.708
0.70		
	Type III Hybrid Vest (307)	0.674
0.60	Type II Standard Foam Yoke (367) (160.052)	0.592
	Horseshoe Type IV	0.568
	Type III Foam Flotation Jacket (302, 370, 371)	0.567
	Type I Standard Foam Yoke (366) (160.055/50/0)	0.508
0.50		
0.40		
0.30	Inflatable Tube in Belt (130)	
	Type III Foam Vest (326, 327)	0.300
	Type IV Cushion (178)	
0.20		
	Inflatable Yoke (152)	0.158
0.10		

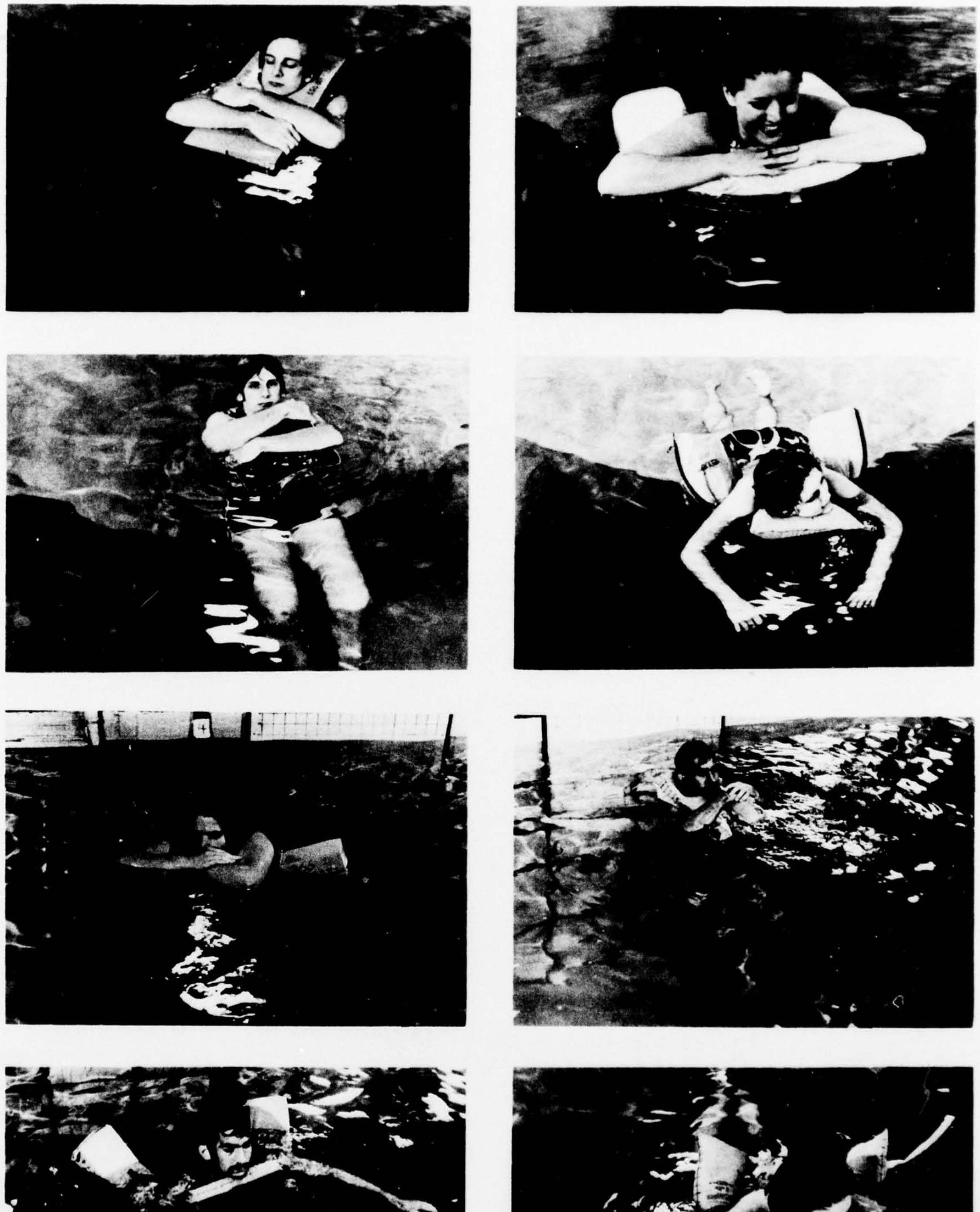


FIGURE IV-18. SOME POSITIONS FOR HOLDING OR LYING UPON PFDS USED BY HUMAN SUBJECTS

3.3 Computation of Probability of Donning (P_D) and Holding (P_H) a PFD In The Water

It was initially assumed that the proportion of accident victims who did not use an accessible PFD after entering the water in a recreational boating accident would be negligible. The probability of donning a specified PFD was therefore taken as P'_D (from Table IV-8) and the probability of holding or laying upon the PFD was taken as $P'_H = (1-P'_D)$. However, several ARM crosstabulations suggest that a large proportion of victims who have a PFD accessible in the water discard the device.

Of all the victims in ARM, 21.6% did not use a PFD even though they had one accessible after the accident. An additional 20.5% of the victims in ARM did not use a PFD even though there was at least one unused PFD aboard the boat (note that "aboard the boat" does not necessarily mean the PFD would be accessible to a victim in the water). Crosstabulations only for those victims who were known to have entered the water were not available. The question of the proportion of victims in the water who discard an accessible PFD should be investigated in the advanced development phase of PFD research. For the present purposes, it was assumed that 30% of those victims in the water who had a PFD accessible did not use the device. Thus, the probability that an accessible PFD is used by a victim in the water, P(U), is 0.70. This value is used for all PFDs since the Boating Accident Reports (BARs) on which ARM is based do not specify type of PFD often enough to allow estimates of P(U) separately for each type of PFD. Methods for estimating P(U) by type of PFD should be investigated in the advanced development phase of PFD research.

In the tests of donning ease conducted in the laboratory, it was implicit that the test subject was supposed to use (not discard) the PFD. The values of P'_D listed in Table IV-8 are therefore taken as estimates of the probability that a specified PFD is donned in the water by a victim given that the victim does not discard the PFD, i.e., P(D/U). From Baye's theorem,

$$P(D \cap U) = P(D/U) \cdot P(U) = P(U/D) \cdot P(D)$$

where D = the event that the PFD is donned by an accident victim after entering the water.

U = the event that the PFD is used by an accident victim after entering the water.

If a PFD is donned, then it must be used, hence, $P(U/D) = 1.0$ and the above equation reduces to:

$$P(D) = P(D/U)\ P(U)$$

Rewriting $P(D)$ as P_D and $P(D/U)$ as P_D', we have:

$$P_D = P_D' \cdot P(U) = 0.7 \cdot P_D'$$

For the probability that a PFD is held or lain upon by a victim after entering the water (P_H), we have:

$$P(H \cap U) = P(H/U) \cdot P(U) = P(H)$$

Rewriting $P(H)$ as P_H and using the fact that $P(H/U) = 1 - P(D/U)$, we obtain:

$$P_H = (1 - P_D') \cdot P(U) = 0.7\ (1 - P_D')$$

The parameters P_D and P_H are used in the LSI computations (see Table VII-2).

4.0 PREDICTION OF PFD EFFECTIVENESS FROM PFD PROPERTIES

The results of predicting PFD effectiveness from the PFD properties were mixed. The effectiveness property of E_{W_B}, the effectiveness of turning a relaxed person to a face-up position as measured by the Head Forward Moving Test of the human subjects, is satisfactorily predicted using PFD properties. However, the prediction of the effectiveness property of E_{W_C}, the effectiveness of maintaining a person in a face-up position as measured by the Head Back Stationary Test of the human subjects, is inconclusive.

An attempt was made to predict E_{W_B} computed from the human subject data by using the physical PFD properties of center of buoyancy and total buoyancy. Table IV-10 shows the results. A turning moment index is derived, which is the total buoyancy multiplied by the z-component of the center of buoyancy for each PFD. The effectiveness, E_{W_B}, is expressed as the proportion of people turned to a face-up position with at least four inches of freeboard, after starting in a head forward, moving attitude.

The z-component only of the center of buoyancy is used for this part, because all PFDs tested during the research were found to be symmetrical with respect to left hand side versus right hand side, thus resulting in a y-component near zero. The y-component, therefore, will be ignored in this analysis. The x-component, while being non-zero did not correlate with effectiveness. This can be seen by observing Figure IV-19, the location of center of buoyancy with respect to the suprasternal notch. The effectiveness number E_{W_B}, shown in parentheses, varies independently of the x-component.

It is seen from Table IV-10 that the Type IV cushion's effectiveness is not adequately predicted by the turning moment index. This was probably due to the fact that it is loosely attached to the body in the human subject tests and in the center of buoyancy apparatus. There is no means for adjusting it to a more fixed location during these tests. Therefore, the remainder of the discussion will ignore the anomaly presented by the Type IV cushion and will concentrate on those types, which are to a certain extent adjustable, and better conform to an individual.

TABLE IV-10. TURNING MOMENT INDEX COMPARED TO EFFECTIVENESS, E_{W_B}

PFD TYPE	TURNING MOMENT INDEX* (TMI)	EFFECTIVENESS, E_{W_B} (HEAD FORWARD MOVING)
Type IV Cushion (178)	92.8	0.20
Type I Standard Foam Yoke (366)	60.6	0.87
Modified Hybrid Vest Inflated (218)	59.9	0.73
Type III Hybrid Vest Inflated (307)	51.0	0.80
Type II Standard Foam Yoke (367)	43.9	0.60
Inflatable Yoke (152)	36.4	0.67
Type II AK-1 (200)	25.0	0.40
Type III Hybrid Vest Uninflated (307)	17.2	0.20
Type III Foam Flotation Jacket (302, 370, 371)	11.4	0
Type III Foam Vest (326, 327)	7.2	0.07
Modified Hybrid Vest Uninflated (218)	4.8	0.13
Inflatable Tube In Belt (130)	0	0

* The total buoyancy of the PFD times the z-component of its center of buoyancy (lbs x inches).

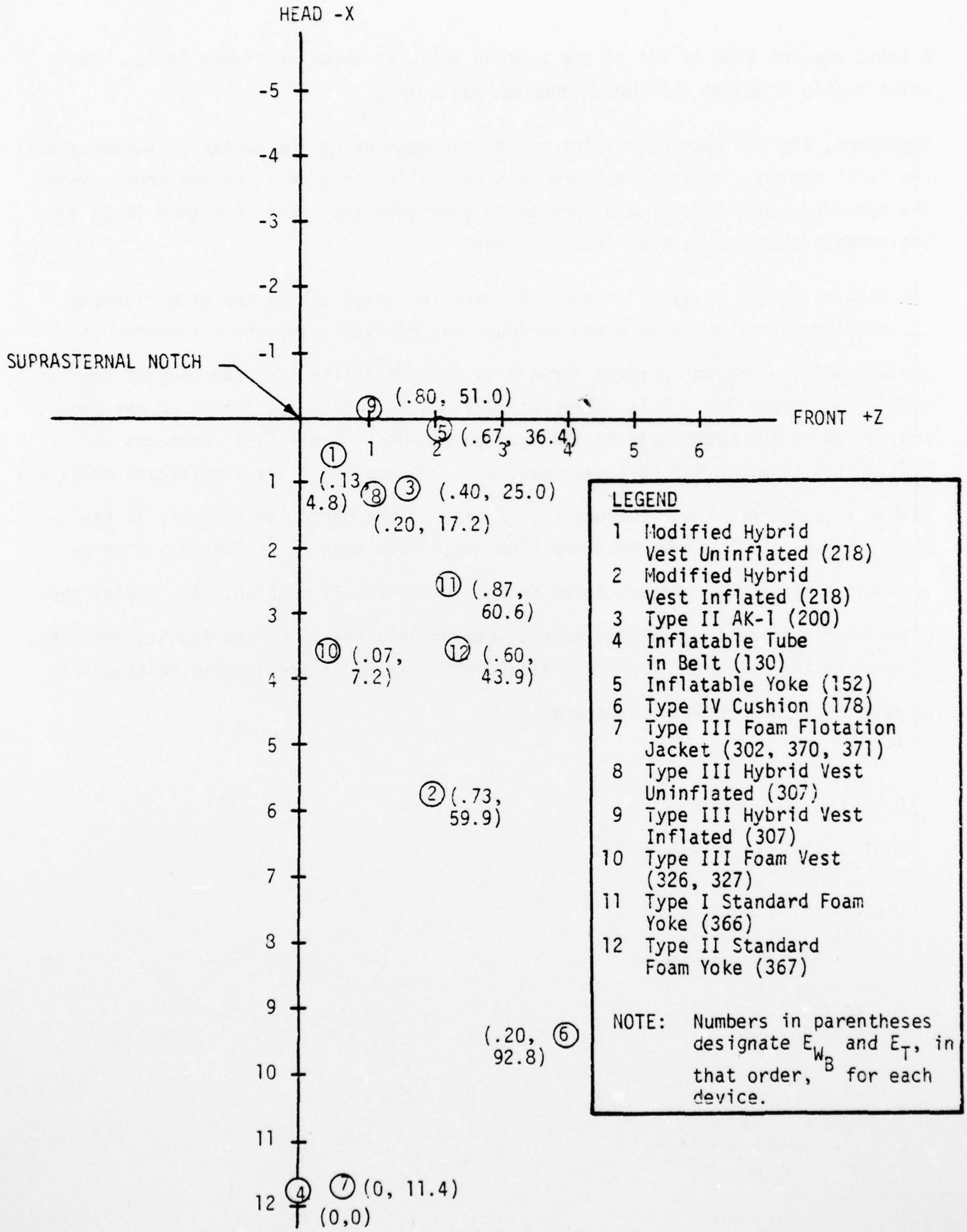


FIGURE IV-19. DISTRIBUTION OF CENTER OF BUOYANCY WITH E_{W_B} (HEAD FORWARD, MOVING)

A least squares line is fit to the plotted data, as shown in Figure IV-20. This relationship accounts for 93% of the variance in E_{W_B}.

Therefore, the PFD characteristics of the z-component of the center of buoyancy and the total buoyancy would be measured and multiplied to give a turning moment index. The turning moment index would then be entered into the chart in Figure IV-20 and the effectiveness, E_{W_B}, read from the chart.

The results of the analysis of the PFD characteristics versus the effectiveness E_{W_C} are inconclusive. A maintaining index was derived using the difference in buoyancy of the buoyant portion forward of the centerline less the buoyant portion behind the centerline. This difference was multiplied by the length of the moment arm, which is the hypotenuse of the x, z-components. Table IV-11 compares the maintaining index to the effectiveness, E_{W_C}. No statistically significant relationship exists between these components. A plot of the center of buoyancy in the x-z plane, Figure IV-21, shows that the PFDs which have high E_{W_C}'s lie in a diverse area and that the E_{W_C} appears to be random. The Type IV cushion, (6), yields the highest moment and the modified hybrid vest uninflated yields the lowest, yet these PFDs yield the lowest E_{W_C}'s. This data does not yield a predictable relationship between the PFD characteristics and E_{W_C}.

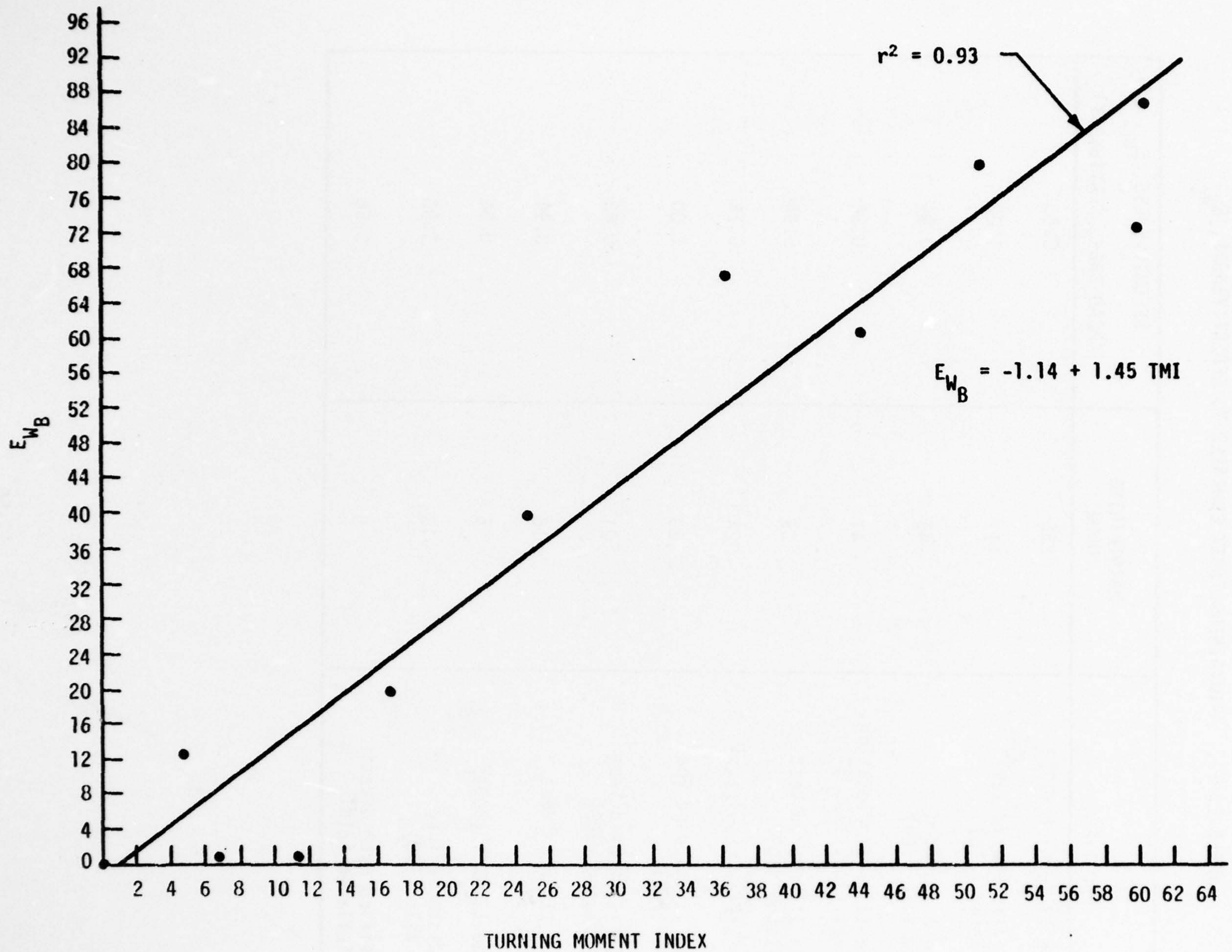


FIGURE IV-20. RELATIONSHIP BETWEEN TURNING MOMENT INDEX AND E_{W_B} FOR SYMMETRICAL PFDS (I.E., Y-COMPONENT OF THE CB≈0)

TABLE IV-11. MAINTAINING INDEX COMPARED TO EFFECTIVENESS, E_{W_C}

PFD TYPE	MAINTAINING INDEX	EFFECTIVENESS, E_{W_C} (HEAD BACK, STATIONARY)
Type IV Cushion (178)	235	0.50
Modified Hybrid Vest Inflated (218)	117	1.00
Type I Standard Foam Yoke (366)	45	0.94
Type III Foam Flotation Jacket (302, 370, 371)	41	0.94
Type III Hybrid Vest Inflated (307)	39	0.94
Inflatable Yoke (152)	24	0.78
Type II Standard Foam Yoke (367)	23	1.00
Type III Hybrid Vest Uninflated (307)	21	0.83
Type III Foam Vest (326, 327)	16	0.94
Type II AK-1 (200)	16	0.94
Inflatable Tube In Belt (130)	-13	1.00
Modified Hybrid Vest Uninflated (218)	5	0.56

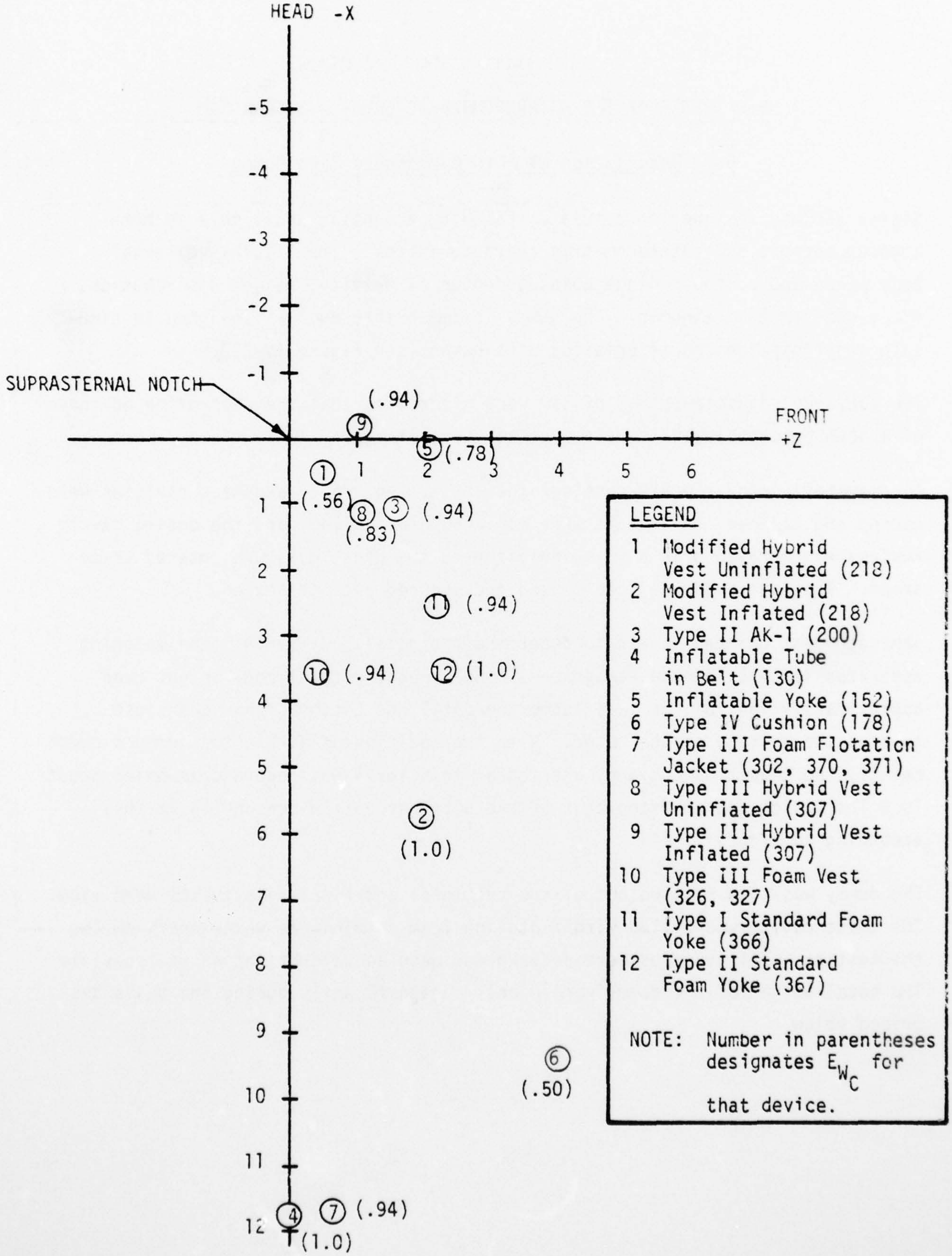


FIGURE IV-21. DISTRIBUTION OF CENTER OF BUOYANCY WITH EFFECTIVENESS, E_{W_C} (HEAD BACK, STATIONARY)

5.0 TESTS OF THE ANTHROPOMORPHIC DUMMY - SIERRA SAM

5.1 Description of Anthropomorphic Test Dummy

Sierra Sam was designed to simulate the 50th percentile adult male in both anthropomorphic and anthropometric characteristics. That is, his external body shape and contour, hinge points, center of gravity, weight distribution, etc., conform to the human. The dummy is immersible and was designed to simulate the flotation characteristics of a human (see Figure IV-22).

The buoyancy characteristics of Sam were altered so that they approximated those of a 50th percentile adult male over 18 years of age.

In preparation for the PFD testing, the chest, leg, foot, and head cavities were opened and cleaned. All seals were replaced and caulked, and the entire cavity surface was sprayed with a rust inhibitor in the event moisture entered these areas. The cavities were then closed and secured but not sealed.

Sam was first weighed in air to determine his total body weight (the weighing apparatus is described in Paragraph 1.3.3. When the total body weight read approximately 155 lbs, Sam was submerged until the bottom of his chin just touched the surface of the water. With the addition of air in the dummy's chest cavity, the amount of buoyancy exerted at this level was recorded as being about 10.5 lbs (which approximated that of the 50th percentile person (10.78 lbs) according to Figure IV-24).

The dummy was then hoisted out of the test pool and final adjustments were made. The chest cavity was filled with flotation foam to minimize water entry during the testing. All cavities were secured and made as water-tight as was possible. The total weight of the dummy varied only insignificantly during the tests described below.

AD-A058 738 WYLE LABS HUNTSVILLE ALA F/G 6/7

PERSONAL FLOTATION DEVICES RESEARCH. VOLUME 2. RESEARCH REPORT.(U)

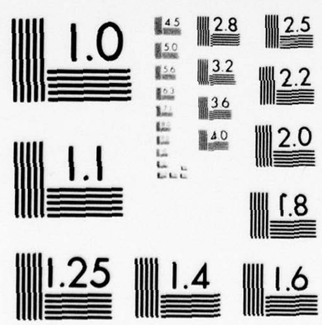
JAN 78 T DOLL, M PFAUTH, J GLEASON, S COHEN DOT-CG-42333-A

UNCLASSIFIED MSR-78-1-VOL-2 USCG-D-41-78-VOL-2 NL

3 OF 6

AD A058738

5873



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

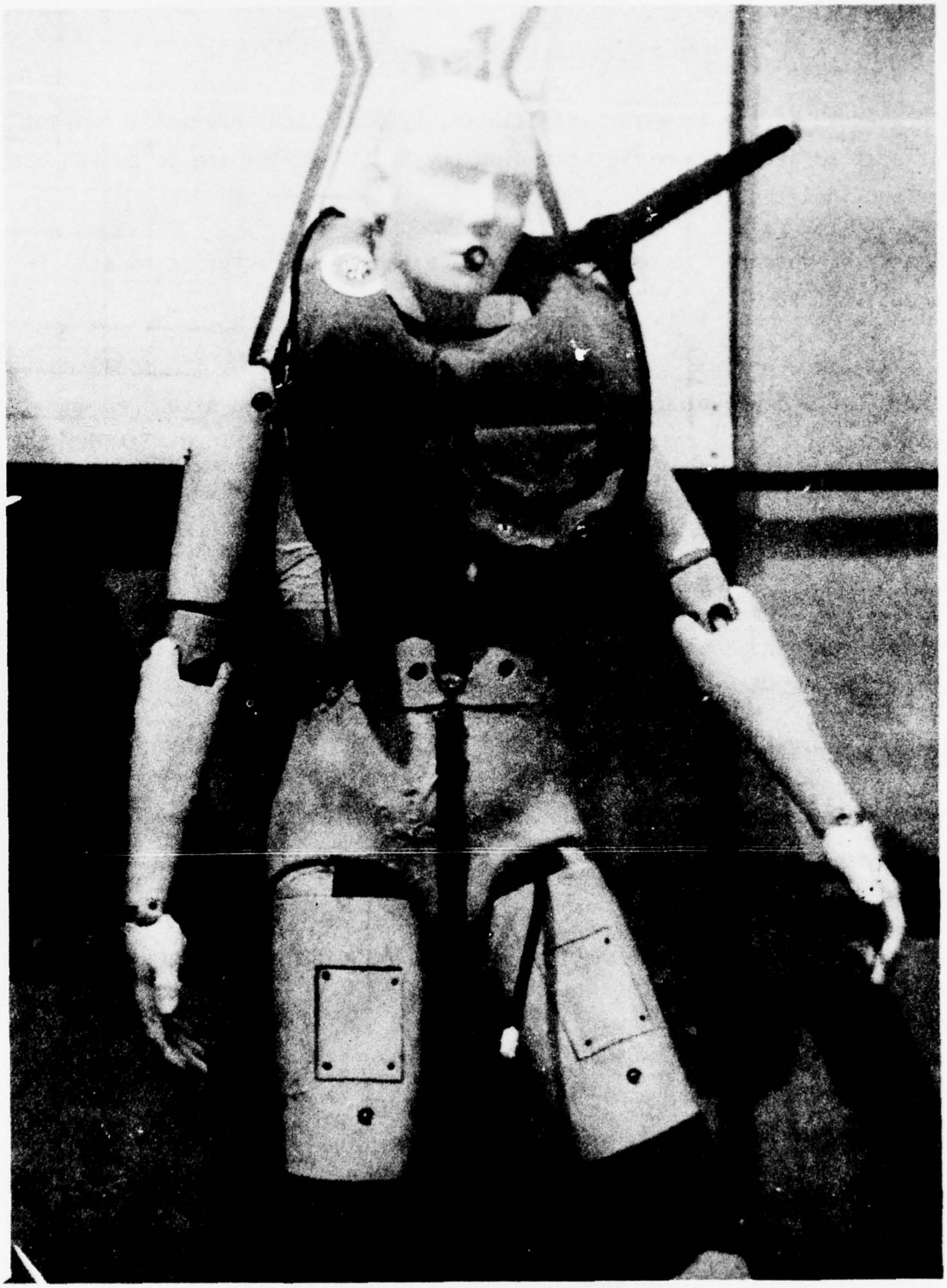


FIGURE IV-22. ANTHROPOMORPHIC TEST DUMMY (SIERRA SAM)

5.2 Test Procedure

The test procedure is the same for inflatables, hybrids, and inherently buoyant PFDs. Inflatables are to be inflated during the test; hybrids are to be run both uninflated and inflated.

Scope: A test is required to measure the effectiveness characteristics associated with a given PFD.

Purpose: This procedure was used to determine the turning time, the final equilibrium angle and the amount of freeboard that is provided by a given PFD and will employ a number of subtests which will position the dummy in different configurations.

Procedure:

1) This test was done in a pool with calm water so that more accurate measurements of freeboard could be made and it was equipped with cameras for above water and below water photographs of the testing.

2) PFD characteristics were unaltered.

3) Calibrate the digital strain gauge by zeroing the low end to read "0" and the high end to read "250." Attach a standard weight to the gauge and note the reading.

4) Attach the dummy harness to the strain gauge hook and record the weight.

5) Submerge the dummy to the chin (until the chin just touches the water surface). Evacuate all air from the dummy by rocking it until no more air bubbles surface. Wait momentarily for the water to calm and then record the reading.

6) Perform the following subtests for each PFD with the aid of an assistant in the water to maneuver the dummy into the below described positions.

   6.1 (Head Forward Stationary Test) - Position the head forward; extend the arms halfway laterally and lean the body forward. The dummy should be

stationary initially. The dummy is then released and its final resting position is photographed with the above and below-water cameras.*

6.2 (Head Back Stationary Test) - Position the head back; extend the arms halfway laterally and lean the body back. The dummy should be stationary initially. The dummy is then released and its final resting position is photographed with the above and below-water cameras.

6.3 (Head Forward Moving Test) - Position the head forward; extend the legs approximately 30° from the horizontal; extend the arms 3/4 laterally. The body should be prone. Apply a pulling force to initiate movement through the water (forward). The pull is accomplished by attaching a rope to the harness and pulling the dummy from poolside. Care was taken to keep the rope as close to the water level as possible so as not to impose an upward force. An effort was made to keep the pull constant for each PFD. The dummy is photographed in its final resting position with the above and below-water cameras.

6.4 (Holding Donned Only Test) - Put the PFD on the dummy but do not fasten it. The PFD is held down by placing the dummy's arms over the chest. The dummy is photographed in its final resting position with the above and below-water cameras.

6.5 (Holding Under Arms Test) - Place the ends of the PFD under the dummy's armpits with the middle of the PFD under his chin. Photograph dummy in final resting position with above and below-water cameras.

6.6 Hoist the dummy out of the water and position him at the edge of the pool. At a signal the dummy was allowed to fall backward into the water from a standing position. Photograph dummy in final resting position with above and below-water cameras.

6.7 Same as 6.6, except the dummy is allowed to fall forward into the pool from a standing position.

---

* All photographs are to be taken with the dummy as close as possible to the grid (without touching) and showing the dummy's profile.

5.3 Dummy Results

The tests were run to determine whether the dummy could reliably reproduce the performance of a human subject of similar dimensions in the water wearing a PFD. Dummy limitations must be recognized at the outset. No matter how sophisticated the dummy, the dynamic properties of the human body cannot be reproduced.

A sample of PFDs of varying design was tested using both the dummy and human subjects. The results are compared in this section to determine whether or not the dummy tests adequately predict the performance of the PFD with an acceptable proportion of the human subjects.

5.3.1 Comparison of Selected 50th Percentile Weight Male Subjects with a 50th Percentile Dummy

For the human subjects, five adult males were selected who ranged from the 31 - 65th percentile weight. The results of tests run using this population sample were averaged and compared to those of the dummy for the Head Forward and Head Back Stationary Tests. One subject, whose buoyancy characteristics very nearly matched those of the dummy, was run and these results are compared for the Head Forward Moving Test and for the Holding tests.

Table IV-12 shows the tabulated results of the subject/dummy comparison by test and PFD. A zero entry in this table indicates that the PFD did not provide adequate freeboard and an acceptable (zero or negative) final equilibrium angle. The minimum freeboard accepted for these tests for human subjects was four inches while dummy requirement was three inches. The reason for the difference in freeboard requirements is that dummy limitations in movement and simulation of human flotation characteristics could very possibly cause a reduction in dummy freeboard. Also, the residual air volume present in the lungs would tend to increase the freeboard in the human subjects. It is, therefore, felt that attainment of a three inch freeboard by the dummy would translate to a four inch freeboard for a human subject.

A "1" entry indicates that freeboard and final equilibrium angle requirements were met. While a head back position is preferred, a head vertical or forward position was also considered acceptable as long as there was adequate freeboard.

TABLE IV-12. COMPARISON OF 50TH PERCENTILE WEIGHT MALE SUBJECTS WITH A 50TH PERCENTILE IMMERSIBLE DUMMY

PFD	TEST									
	Head Forward[c] Stationary		Head Back[c] Stationary		Head Forward[c] Moving		Holding[d] - Donned Only		Holding[d] - Under Arms	
	Pred[a]	Obs[b]	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs
Type I Standard Foam Yoke (066)	1	1	1	1	1	1	1	0	1	0
Type II Standard Foam Yoke (067)	0	0	1	1	0	1	0	0	0	0
Type II MK-1 (200)	0	0	1	1	0	1	0	0	0	0
Type III Foam Vest (022, 027)	0	0	1	1	0	0	0	1	0	0
Type III Foam Flotation Jacket (302, 370, 371)	0	0	1	1	0	0	1	1	0	0
Type IV Cushion (178)	0	0	1	1	0	0	0	0	0	0
Type III Hybrid Vest Uninflated (307)	0	0	1	1	0	0	1	1	1	0
Type III Hybrid Vest Inflated (307)	0	0	1	1	0	1	1	0	0	1
Modified Hybrid Vest Uninflated (210)	0	0	0	0	0	0	0	0	0	0
Modified Hybrid Vest Inflated (210)	1	0	1	1	0	1	1	1	0	0
Inflatable Yoke (152)	0	0	1	1	0	1	0	0	1	0
Inflatable Tube In Belt (130)	0	0	1	1	0	0	1	1	0	0

[a] Pred = Dummy results

[b] Obs = Human subject results - "0" means the PFD was effective for <50 percent of the human subjects; "1" means the PFD was effective for ≥ 50 percent of the subjects.

[c] For male subjects from 31-65 percentile body weight.

[d] For one human subject with buoyancy requirement of 10.7 lbs to the chin.

0 = <4 in. freeboard for human subjects, <3 in. freeboard for dummy and did not maintain a face-out-of-water position.

1 = ≥4 in. freeboard for human subjects, ≥3 in. freeboard for dummy and did maintain a face-out-of-water position.

Only 1 of the 12 PFD configurations satisfied the freeboard and equilibrium angle requirements for the human subjects in the Head Forward Stationary Test (Table IV-12). The performance of the dummy matched that of the human subjects for 11 of the 12 PFD configurations. For the Head Back Stationary Test, 11 of the 12 PFD configurations exhibited acceptable performance. In this case, the performance of the dummy matched that of the human subjects in all 12 PFD configurations.

In the Head Forward Moving Test, 6 of 12 PFD configurations exhibited acceptable performance with human subjects, but only 1 PFD configuration gave acceptable performance with the dummy. It should be kept in mind that this test required a 2-1/2 breast stroke by the subject and then relaxation, with the arms half extended laterally. An attempt to simulate this motion was accomplished by attaching a rope to the dummy harness and pulling it through the water. Although the dummy had adjustable friction plates to control the ease of movement of its limbs, the friction could not be reduced to match that of a relaxed human subject without risk of the dummy's limbs falling off. It was also observed that the dummy's neck did not exhibit the same kind of motion as that of a relaxed human subject. The dummy's neck tended to spring back when pushed forward or back and did not move as freely as a relaxed human's neck. The use of a dummy whose limbs and neck could be made to move more freely might greatly improve the dummy's ability to predict PFD effectiveness in the Head Forward Moving Test and the holding tests.

The human subjects and dummy performed similarly in one holding test but not in the other holding test. When the PFD was donned but not fastened, 6 of 12 PFDs performed satisfactorily with the dummy and 5 of 12 performed adequately with the human subjects. Four out of six PFDs (those cases where performance was satisfactory) were effective for both the dummy and the human subject. When the PFD was held under the arms, 3 of 12 PFDs performed satisfactorily with the dummy and 1 of 12 PFDs performed adequately with the human subjects. In no case is the same PFD effective for both the dummy and human subjects in this test.

Based on the tabulated results in Table IV-12 the following conclusions are given:

1) The 50th percentile dummy adequately reproduced 50th percentile human subject results for the Head Forward and Head Back Stationary Tests and for the Holding Donned Only Test.

2) The 50th percentile dummy did not reproduce the 50th percentile human subject results for the Head Forward Moving Test, and the Holding Under Arms Test.

5.3.2 Comparison of All Subjects with a 50th Percentile Immersible Dummy

The subjects used in these tests ranged from 2nd to 98th percentile and included both males and females. The results presented in Table IV-13 compare data collected for human subject performance and that collected for the dummy. The "0" and "1" entries are indicative of freeboard and equilibrium requirement and an explanation appears below the table.

As can be seen in Table IV-13, the dummy results very closely approximate those for the human subjects. The PFDs were effective in 2 out of 12 cases for the dummy and 2 out of 12 cases for the human subjects for the Head Forward Stationary Test. The performance of the dummy matched that of the human subjects for all 12 PFD configurations. For the Head Back Stationary Test, 11 of the 12 PFDs were effective for the dummy and all 12 PFDs were effective for the human subjects. For the Head Forward Moving Test, 1 of 12 PFDs was effective for the dummy and 5 of 12 were effective for the human subjects. The holding test results are identical to those in the previous table since in both cases they are based on one 50th percentile buoyancy requirement human subject.

Based on these results, the following conclusions are offered:

1) The 50th percentile dummy adequately predicted the performance of the 12 PFD configurations tested for all human subjects in both the Head Forward Stationary Test and the Head Back Stationary Test.

2) The 50th percentile dummy did not predict the performance of the PFDs for all subjects in the Head Forward Moving Test.

TABLE IV-13. COMPARISON OF ALL SUBJECTS WITH A 50TH PERCENTILE IMMERSIBLE DUMMY

PFD	TEST									
	Head Forward Stationary		Head Back Stationary		Head Forward Moving		Holding[d] - Donned Only		Holding[d] - Under Arms	
	Pred[a]	Obs[b]	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs
Type I Standard Foam Yoke (366)	1	1	1	1	1	1	1	0	1	0
Type II Standard Foam Yoke (367)	0	0	1	1	0	1	0	0	0	0
Type II AK-1 (200)	0	0	1	1	0	0	0	0	0	0
Type III Foam Vest (326, 327)	0	0	1	1	0	0	0	1	0	0
Type III Foam Flotation Jacket (302, 370, 371)	0	0	1	1	0	0	1	1	0	0
Type IV Cushion (178)	0	0	1	1	0	0	0	0	0	0
Type III Hybrid Vest Uninflated (307)	0	0	1	1	0	0	1	1	1	0
Type III Hybrid Vest Inflated (307)	0	0	1	1	0	1	1	0	0	1
Modified Hybrid Vest Uninflated (218)	0	0	0	1	0	0	0	0	0	0
Modified Hybrid Vest Inflated (218)	1	1	1	1	0	1	1	1	0	0
Inflatable Yoke (152)	0	0	1	1	0	1	0	0	1	0
Inflatable Tube in Belt (130)	0	0	1	1	0	0	1	1	0	0

[a] Pred = Dummy results

[b] Obs = Human subject results - "0" means the PFD was effective for <50 percent of the human subjects; "1" means the PFD was effective for ≥ 50 percent of the subjects.

[d] For one human subject with buoyancy requirement of 10.7 lbs to the chin.

0 = <4 in. freeboard for human subjects, <3 in. freeboard for dummy and did not maintain a face-out-of-water position.

1 = ≥4 in. freeboard for human subjects, ≥3 in. freeboard for dummy and did maintain a face-out-of-water position.

5.3.3 Comparison of Subjects in 50th Percentile Requirement Range with a 50th Percentile Buoyancy Requirement Immersible Dummy

The subjects used in these comparisons were those males and females in the human subject effectiveness tests who had a buoyancy requirement in the 50% range (9.8 to 11.8 lbs added buoyancy required to support the subject above the chin). The results are shown in Table IV-14. Again, the dummy adequately predicted the Head Forward Stationary results and Head Back Stationary results, but not the results of the Head Forward Moving Test.

TABLE IV-14. COMPARISON OF 50% BUOYANCY REQUIREMENT SUBJECTS WITH A 50TH PERCENTILE BUOYANCY REQUIREMENT IMMERSIBLE DUMMY

PFD	TEST									
	Head Forward[c] Stationary		Head Back[c] Stationary		Head Forward[c] Moving		Holding[d] - Donned Only		Holding[d] - Under Arms	
	Pred[a]	Obs[b]	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs
Type I Standard Foam Yoke (366)	1	1	1	1	1	1	1	0	1	0
Type II Standard Foam Yoke (367)	0	0	1	1	0	1	0	0	0	0
Type II AK-1 (200)	0	0	1	1	0	0	0	0	0	0
Type III Foam Vest (326, 327)	0	0	1	1	0	0	0	1	0	0
Type III Foam Flotation Jacket (302, 370, 371)	0	0	1	1	0	0	1	1	0	0
Type IV Cushion (170)	0	0	1	0	0	0	0	0	0	0
Type III Hybrid Vest Uninflated (307)	0	0	1	1	0	0	1	1	1	0
Type III Hybrid Vest Inflated (307)	0	0	1	1	0	1	1	0	0	1
Modified Hybrid Vest Uninflated (210)	0	0	0	0	0	0	0	0	0	0
Modified Hybrid Vest Inflated (210)	1	0	1	1	0	1	1	1	0	0
Inflatable Yoke (152)	0	0	1	1	0	1	0	0	1	0
Inflatable Tube In Belt (130)	0	0	1	1	0	0	1	1	0	0

[a] Pred = Dummy results

[b] Obs = Human subject results - "0" means the PFD was effective for <50 percent of the human subjects; "1" means the PFD was effective for ≥ 50 percent of the subjects.

[c] For the three human subjects tested whose buoyancy requirements to the chin were between 9.7 and 11.7 lbs.

[d] For one human subject with buoyancy requirement of 10.7 lbs to the chin.

0 = <4 in. freeboard for human subjects, <3 in. freeboard for dummy and did not maintain a face-out-of-water position.

1 = ≥ 4 in. freeboard for human subjects, ≥ 3 in. freeboard for dummy and did not maintain face-out-of-water position.

6.0 COMPARISON OF DUMMY AND PFD PROPERTIES METHODS

The anthropomorphic dummy adequately simulated the performance of the PFDs tested in this study with human subjects for the Head Forward Stationary (E_{W_A}) and Head Back Stationary (E_{W_C}) Tests and the Holding Donned Only Test. The dummy did not adequately simulate human subject performance in the Head Forward Moving Test (E_{W_B}) and in the Holding Under Arms Test. The PFD properties method adequately predicted human subject results for the Head Forward Moving Test (E_{W_B}) but not for the Head Back Stationary Test (E_{W_C}).

The two methods for predicting effectiveness could be used in combination, yielding accurate measures of both E_{W_B} and E_{W_C}. This, of course, would be a relatively costly approach. Alternatively, further development work might be undertaken to perfect one of the two (or possibly both) methods. Of the two methods, the dummy seems to offer the most promise. A major problem noted in using the dummy in the Head Forward Moving and Holding Tests was that its limbs and neck did not move as freely as those of a relaxed human subject. Remedying this problem might greatly improve the predictive capability of the dummy in these tests.

Since the dummy method seems most promising, the preliminary test procedure has been written around this method for estimating the effectiveness of PFDs when worn (E_{W_B}, E_{W_A}, E_{W_C}) and when held (E_H).

It is recommended that a group of dummies representing the full range of buoyancy requirement for human subjects be used to estimate effectiveness numbers for candidate PFDs. It is advisable to match the dummies to human buoyancy requirements rather than total body weight. It was found that total body weight was only very weakly associated with buoyancy requirements. This can be seen in Figure IV-23 which compares the distribution of buoyancy requirements for various percentiles of the population by weight. The range of buoyancy requirements overlap considerably in each of the various weight percentiles, and there is no statistically significant trend between smaller and larger weight percentiles. Therefore, the population tested is considered to be a random sample of buoyancy requirements. Using the same data, a cumulative probability distribution for buoyancy requirements is developed and depicted in Figure IV-24.

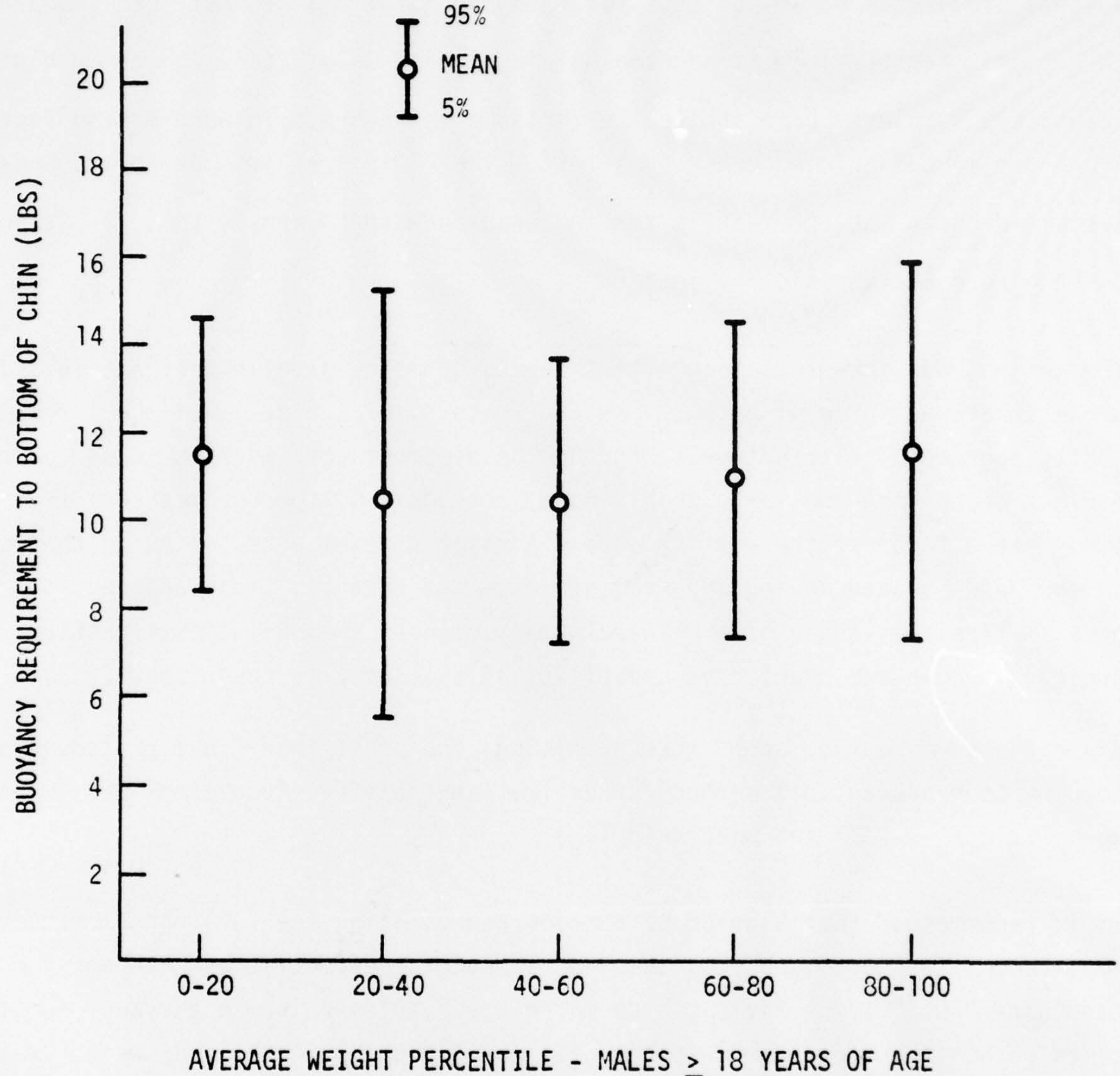


FIGURE IV-23. DISTRIBUTION OF BUOYANCY REQUIREMENTS VS. AVERAGE WEIGHT PERCENTILE FOR COMBINED WYLE AND ADL (REFERENCE 1) DATA

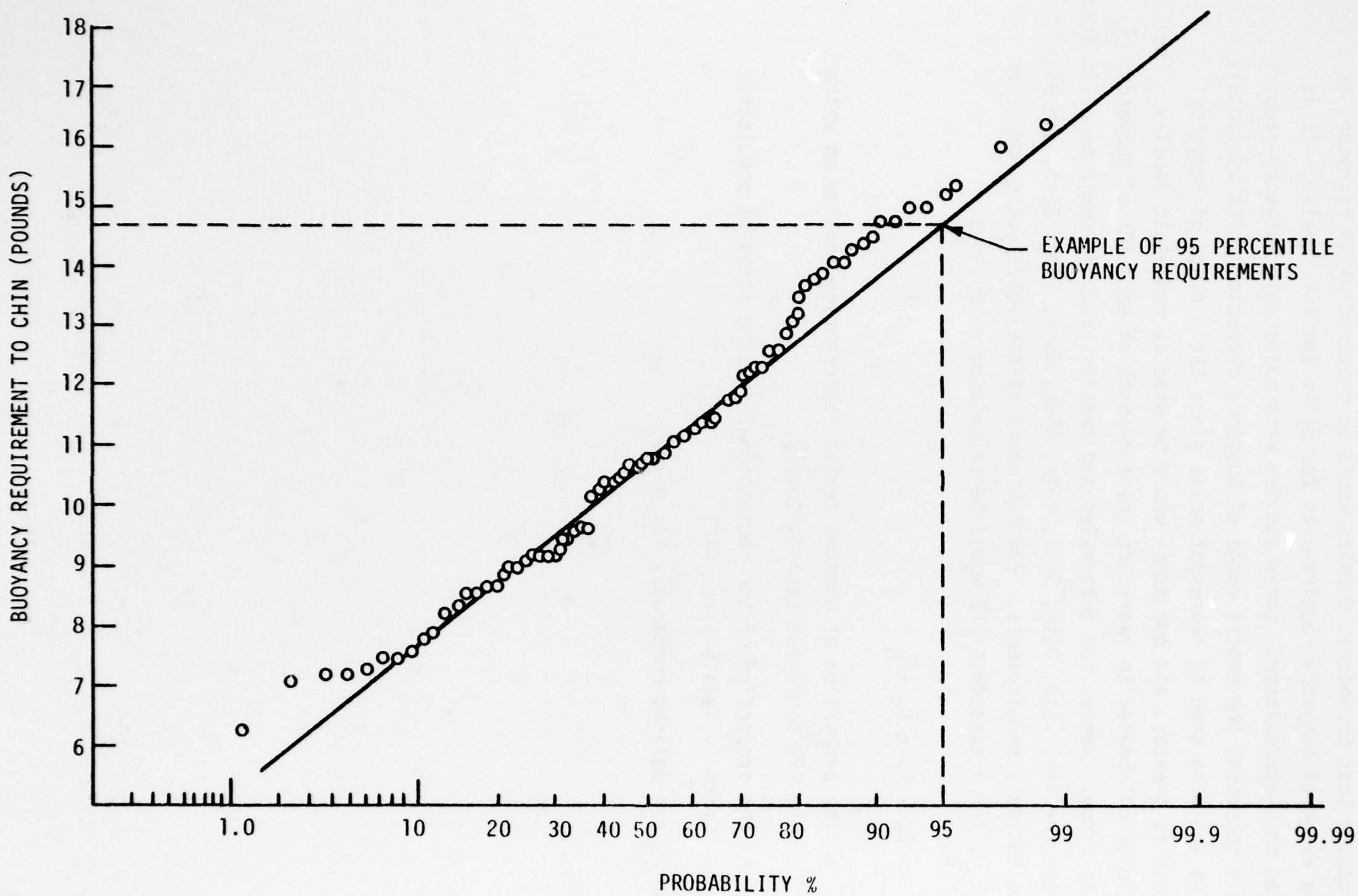


FIGURE IV-24. CUMULATIVE PROBABILITY DENSITY FUNCTION FOR BUOYANCY REQUIREMENT (MALE $\geq$ 18 YEARS OF AGE)

In the proposed test procedure, dummies would be procured which represent each 10% of the range of buoyancy requirements for males and for females. It is anticipated that approximately three dummies with adjustable buoyancy requirements could represent the entire range of buoyancy characteristics adequately. Two dummies would be used to represent males since their range of buoyancy requirements is greater, and one dummy would be used to represent females. The dummy would be calibrated to represent the mid-point of each 10% of buoyancy requirement range. Hence, for both males and females, dummies would be calibrated to represent the 5th, 15th, 25th, 35th, 45th, 55th, 65th, 75th, 85th, and 95th percentile buoyancy requirements. The estimated effectiveness when worn (for example, E_{W_B}) for a candidate PFD would be calculated as follows:

$$E_{W_B} = E_F \cdot P_F + E_M \cdot P_M$$

where E_F = the proposition of dummies tested representing females on which the PFD performed satisfactorily.

P_F = the proportion of the recreational boating accident population which is female (from ARM)

and E_M and P_M are defined comparably for males.

7.0 EFFECTIVENESS TEST PROCEDURE AND RECOMMENDATIONS

The recommended effectiveness plan is shown in Figure IV-25 and explained in the following subsections.

7.1 Security of Fit and Inflation Time*

The PFD shall be equipped with means for size adjustment or be designated per size so that it can be made to fit the wearer securely. It shall be incapable of displacement about the wearer in any way that could impair its performance.

This property is tested for by using two human subjects representing the 10th and 90th percentile by weight or by 2 human subjects within 10% of the smallest and largest size dimensions which the PFD properly fits. Each subject will fall backward into the water as described in Paragraph 3.0 and step forward into the water from a surface 6 in. above the water level. An assessment shall be made by an observer based upon the performance of the candidate PFD to the performance of four reference PFDs. The candidate PFD will then be judged to have passed or failed. The subjects shall operate manually actuated devices immediately after entering the water. The subjects shall be unfamiliar with the device and shall not be holding the actuator mechanism as they fall into the water. Time from the subject's first contact with the water until full inflation shall be recorded and compared to a minimum value.

7.2 Probability of Donning in the Water*

The purpose of this test is to ascertain the probability that an accident victim will be able to don the PFD in the water.

It is accomplished by using two human subjects representing the 10th and 90th percentile by weight or by 2 human subjects within 10% of the smallest and largest size dimension which the PFD properly fits, who have been selected by controlling for swimming ability. Subjects shall be selected who report that they can tread water for 2 minutes or more but have not swum competitively. The candidate PFD will be tossed to the subjects while they are in the water and the observer will compare the performance of the candidate PFD to the performance of five reference PFDs with respect to a donning time and difficulty rating.

---

* Prior to testing a candidate PFD, the human subjects shall practice each test at least once with each of four styles of PFDs: 1) vest, 2) jacket, 3) yoke, and 4) belt.

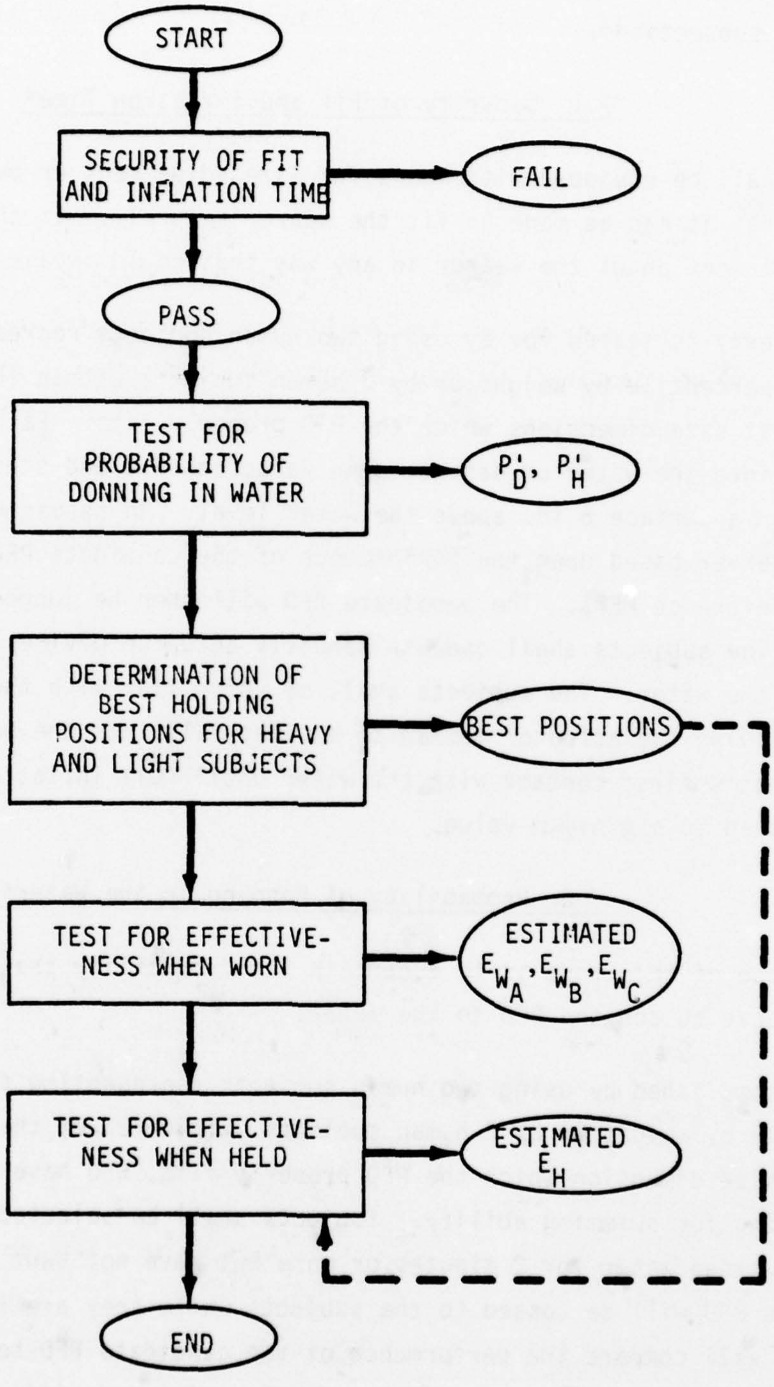


FIGURE IV-25. EFFECTIVENESS TEST PROCEDURE PLAN

The candidate PFD then will be given an estimated value of the Probability of Donning in the water, P'_D by comparing the average rating given the candidate PFD to the ratings of reference PFDs (see Table IV-8). The probability of holding, P'_H, is $1 - P'_D$.

7.3 Determination of Best Positions for Holding PFD for Heavy and Light Subjects*

The best two or three positions for laying upon or holding the candidate PFD without grasping will be determined by using two human subjects representing the 10th and 90th percentile by weight.** While the subjects are relaxed, they will hold or lay upon the candidate PFD in varied positions until it is determined which positions best maximize freeboard and stability. Those positions will be recorded.

7.4 Effectiveness when Worn

The purpose of this test is to estimate the effectiveness of the candidate PFD when worn to provide the wearer with a minimum of 4 in. freeboard.

Two effectiveness numbers are estimated to assess the cases of turning an unconscious or exhausted wearer to a face-up attitude, E_{W_A} and E_{W_B}, and maintaining a wearer in a face-up attitude, E_{W_C}.

The test is accomplished by using a group of anthropomorphic dummies who simulate the buoyancy characteristics of the 5th, 15th, 25th, 35th, 45th, 55th, 65th, 75th, 85th, and 95th buoyancy requirement to support the wearer above the chin for males and for females† (20 dummy configurations in all).††

---

* Prior to testing a candidate PFD, the human subjects shall practice each test at least once with each of four styles of PFDs: 1) vest, 2) jacket, 3) yoke, and 4) belt.

** Size is not considered in this test since a PFD may be thrown to a person in the water during an accident without regard to size.

† Based on residents of the United States of America 18 years or age and over.

†† The candidate PFD will be tested on only those dummy configurations which it properly fits.

A candidate PFD is properly donned and fully fastened on each dummy configuration and subjected to:

Case A: Head Forward, Stationary Test for E_{W_A},

Case B: Head Forward, Moving Test for E_{W_B}, and

Case C: Head Back, Stationary Test for E_{W_C}.

The estimates of E_{W_A}, E_{W_B}, and E_{W_C} are computed as discussed in Paragraph 6.0.

7.5 Effectiveness when Held

The purpose of this test is to estimate the effectiveness of a candidate PFD when it is held or lain upon to provide a minimum of 4 in. of freeboard.

The test is accomplished by using a group of anthropomorphic dummies who simulate the buoyancy characteristics of males and females as detailed in Paragraph 7.4.

A candidate PFD is held or lain upon in all of the positions determined from Step 7.3 by each dummy configuration. Effectiveness when held is computed using an equation analogous to that for effectiveness when worn shown in Paragraph 6.0.

REFERENCES

1. Arthur D. Little, Inc., Buoyancy and Stability Characteristics of the Human Body in Fresh Water, 1972. NTIS No. AD-708-188.

2. Dayton, R. B., Study of the Hydrostatic Moments of the Human Body and PFD, Operations Research, Inc., 1974.

3. Underwriters Laboratories, Investigation of the Performance of Personal Flotation Devices, August, 1975. NTIS No. AD-A017-101.

4. Operations Research, Inc., A Study of Factors Influencing the Wearability of PFD's in Recreational and Work Environments, 1974, NTIS No. AD-A011-211.

5. Bryk, J. A. and Schupack, S. A., Boating Safety: The Use of Personal Flotation Devices, National Safety Council, September, 1974.

SECTION V

DEVELOPMENT OF RELIABILITY TEST METHODOLOGY FOR PFDS

INTRODUCTORY SUMMARY

The Life-Saving Index (LSI) System combines the major components of wearability, effectiveness, and reliability into a model which can be used to evaluate the life saving capability of PFDs while making changes in the three major components.

The reason that reliability is included in the model is that it was theorized that if an advanced conceptual PFD design such as a PFD whose buoyancy was the result of an inflated chamber, hereafter defined as an inflatable PFD, could be developed, that the size, bulkiness and appearance would be such that more recreational boaters would be inclined to wear this style PFD. It was further theorized that this increased wear rate could save many lives. It was argued, however, that these new inflatable PFDs may be less reliable than the existing USCG approved PFD designs whose buoyancy is a result of being manufactured with components which are naturally buoyant, hereafter defined as an inherently buoyant PFD.

It was necessary, therefore, to quantify the reliability of PFDs so that the LSI System could evaluate these theories and arguments to determine whether or not potential lives could be saved by the introduction of new advanced concepts.

Reliability is defined as the probability of a PFD to perform its function of providing adequate buoyancy without failure under given recreational boating conditions for a given period of time. It is recognized from this definition that even an inherently buoyant PFD would become unreliable if it failed to provide adequate buoyancy for the wearer for the entire duration for which he may need it. Reliability, therefore, is concerned with the functioning of the PFD for its useful life in the recreational boating environment. It places new requirements on approval standards to be able to adequately evaluate a PFD for its useful life in its intended environment.

These problems necessitated that a methodology be developed which could evaluate a PFD when it was subjected to an environment indicative of recreational boating and that a figure of merit be given based upon how well the PFD performs.

The first part of this section addresses the development of a test sequence which simulates the recreational boating environment. This is done using currently USCG approved inherently buoyant PFDs since PFDs which have been used by recreational boaters can be compared objectively to PFDs which are subjected to a simulated recreational boating environment, and this simulated artificial environment is adjusted until it truly simulates the recreational boating environment. This use of artificial environments to simulate real world environmental stresses necessitates careful analysis of failure modes and mechanisms to assure that the environment is adequately simulated.

The second part of this section is the reliability analysis of inflatable and hybrid PFDs. The analysis of these styles requires that the simulated environment determined for certain inherently buoyant PFDs be supplemented with environmental factors which are uniquely detrimental to the reliability of inflatable PFDs.

A comparison is made of the existing specifications on inflatable PFDs, which include Australian, British, Canadian, Federal Aviation Administration and Navy specifications. These specifications generally limit themselves to testing of the design characteristics and do not provide for an assessment of the reliability. Therefore, a Reliability Test Plan had to be developed which would test the susceptibility of inflatables to extremes of the recreational boating environment. The results of inflatable PFDs subjected to this test plan showed that an Accelerated Testing Technique is feasible for testing inflatable PFDs, that latent failure modes, which were either manufacturing or design problems, were transformed into detectable failures by the environmental stresses, and that the state-of-the-art for selected types of inflatables is such that these types of inflatables are reliable.

Therefore, an Accelerated Aging Test Sequence was developed which is applicable to inherently buoyant, inflatable and hybrid PFDs. The test results of PFDs subjected to the Accelerated Test Sequence are then inserted into a Reliability Prediction Model to arrive at a Reliability Index which can be used to compare styles, safety features and manufacturers.

Also included in this section are estimates of the reliability of those devices tested, an analysis of the failure modes and effects, which is used to recommend actions to minimize these failure modes, and an analysis of inflation systems.

The objective of this study has been to predict reliability of PFDs in the most severe conditions that could reasonably be expected in recreational boating. Therefore, it has been assumed that PFDs would receive little or no maintenance. This assumption is probably true for the bulk of PFDs in use, or potentially in use, in recreational boating. The question of the maintainability (meaning the ease with which the system can be maintained) of PFDs was clearly beyond the scope of the present project. In addition, the purpose of this or any reliability test procedure is to be able to identify and predict latent failure modes. This assures the consumer of a high probability of obtaining and using a safe and reliable product. However, like all products, it is important that the consumer be able to recognize the importance of good maintenance in both maintaining product reliability and extending its useful life. The ability of a consumer to be able to recognize when a product has reached the end of its useful life or that a failure is imminent is important. The degree to which a particular type of PFD will display either a failure mode or end of useful life characteristic varies. This aspect of PFD use and its impact on the reliability of the PFD population currently in use needs to be considered in future work.

The reliability indices estimated here for inflatable and hybrid PFDs assume that the devices have not been previously actuated, or that if they have been previously actuated, that the users have replaced the CO_2 cylinders or other expendable components.

SECTION V(A)

THE DEVELOPMENT OF A RELIABILITY TEST METHODOLOGY FOR INHERENTLY BUOYANT PFDS

TABLE OF CONTENTS

SECTION V(A) TABLE OF CONTENTS, Concluded

SECTION V(A) LIST OF FIGURES

SECTION V(A) LIST OF FIGURES, Concluded

SECTION V(A) LIST OF TABLES

SECTION V(A)

THE DEVELOPMENT OF A RELIABILITY TEST METHODOLOGY FOR INHERENTLY BUOYANT PFDS

1.0 BACKGROUND REVIEW

1.1 Introduction

As a result of the rapidly advancing technologies in the area of plastics, foam products and related materials, the manufacture of new types of PFDs has seen a substantial increase over the past several years. The United States Coast Guard has recognized that as the market for new PFDs expands rapidly, a method is needed for comparing the advantages and disadvantages of new designs. One of the most important areas is in the design and manufacture of a reliable PFD. The USCG recognizes the importance of encouraging manufacturer creativity in PFD design but at the same time maintaining a high level of reliability. Therefore, the Coast Guard is interested in developing a test methodology that would prove to be flexible enough to apply to a wide variety of PFD designs but at the same time capable of differentiating a reliable design from an unreliable design.

1.2 Review of Testing Methodologies

Basically, there exist two test/design approaches to designing a product: 1) construction standards, 2) performance standards. Construction standards consist of specifications of approved materials and methods that can be used in the design and construction of the finished product. Construction methods are currently used on some types of PFDs, such as Type II PFDs, and are well suited to products of restricted design such as these. The Coast Guard recently undertook research to explore the feasibility of applying reliability methods to construction standards (Reference 1). The results showed that the application of reliability methods to construction standards was infeasible due to the type and amount of data needed from manufacturers. In addition, it was not clear whether the reliability of the whole product could be predicted from the parts. With these limitations in mind, the Coast Guard has undertaken the current work to explore the feasibility of developing performance standards for PFDs. Underwriter's Laboratories has employed the use of both construction standards (UL 1123) and performance oriented standards (UL 1191).

Performance standards are based on the concept that the finished product must meet some minimum standards in regards to the task it is designed for. If the finished product meets these minimum performance requirements, then it has satisfied the standards. Obviously, performance standards such as these have several advantages:

1. Performance standards permit a manufacturer to exercise significant design flexibility.

2. The evaluation of the PFD is based on the performance of the entire system; therefore, emphasis can be placed on those components most closely associated with the reliability.

3. New designs can be easily evaluated and compared to one another.

4. Performance tests can be designed to be representative of the conditions which the product is normally exposed to. This permits the elimination of unnecessary testing.

1.3 Quality Control and Reliability

Both reliability and quality control testing are necessary components in the design and manufacture of PFDs. Confusion often exists as to the relationship between quality control and reliability. One author[1] describes the relationship as follows:

> "Product quality is generally defined as the condition of the product with respect to applicable specifications at a particular time of evaluation. Reliability, in general terms which do not conflict with the mathematical definition, is the capability of a product to continue to meet applicable requirements in usage.
>
> In a sense, a reliability problem is really a quality problem of a special type. During product evaluation, a characteristic may test within specifications and yet bear a latent tendency toward gradual or sudden change; the essence of a reliability problem is this latent tendency toward change. Since this latent condition already exists in a characteristic when it is inspected, the desired quality is not really present at the time of acceptance. Unfortunately, a normal inspection is not capable of detecting this tendency. The application of "reliabilty," then, is a specialized form of "quality" which deals with defects of latent change -- defects which are not visible to traditional quality assurance methods."

[1] Reliability Handbook, edited by W. Grand Ireson, Chapter 13, "Reliability Considerations for Production," by James A. Marshik.

This discussion points out the importance of developing both quality control and reliability procedures. Quality control procedures by themselves are insufficient to assure the boating public of a safe and effective PFD.

1.4 Problem Outline

The development of a valid reliability test procedure requires an ability to predict a probability of performing satisfactorily after a period of usage. One method for determining reliability, therefore, would be to simply expose a sample of devices to normal usage conditions and determine the percentage operating properly after a period of time. The problem with this method is that the time needed to run the test is much too long. A method is required to accelerate the aging process of the device and therefore reduce the test time needed. If the length of time needed for aging a device can be reduced significantly, then the cost required to satisfactorily evaluate reliability is reduced. This report is concerned with the development of this accelerated aging sequence and the associated tests required to evaluate reliability.

1.5 Definition of PFD Reliability

The general definition of PFD reliability that has been used in this research is as follows:

> The reliability of a device is the probability that it will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended.

A much more detailed discussion of the PFD reliability definition is presented in Appendices V(A)-A and V(A)-B.

This definition of PFD reliability points out two important areas that need to be covered in this research:

- The PFD reliability test plan must be capable of predicting PFD performance after some period of usage.
- The PFD reliability test plan must relate reliability testing to actual PFD performance.

The following research effort deals with these areas.

1.6 Literature Review

A literature search and review was conducted in order to obtain information in the following areas:

- the methodology involved in the development of an accelerated aging sequence
- any environmental testing done on PFDs or on products used in PFDs
- reliability tests that have been performed on PFDs or on products used in PFDs

The results of this literature search and review and a methodology for performing accelerated aging have been published in Appendices V(A)-A and V(A)-B. Appendix V(A)-C details other factors affecting buoyancy measurements. A summary of the methods, sources used and major findings are reported here.

Via the Redstone Scientific Information Services, Redstone Arsenal, Huntsville, Alabama, word searches were conducted in the three areas discussed above and in any areas remotely related to these. These searches accessed both the Defense Documentation Center and the National Aeronautics and Space Administration technical services. In discussion with reference librarians, it was decided that the most expedient method for obtaining the relevant information was to access these two agencies. These two agencies are a subset of information available through NTIS, but they represent all agencies (Air Force, Navy, Army, NASA) that were felt to contain relevant information. From these, computer printouts of hundreds of related abstracts of articles were received and reviewed. Articles that were of interest were obtained and reviewed for relevant material.

Secondly, a list of all Coast Guard certified manufacturers of foam material for use in PFDs was compiled and the manufacturers contacted. Information on reliability and environmental testing of their product was solicited. Contact was also made with any other agencies that might use PFDs or be involved in the testing of them. This included several foreign countries and their associated test agencies.

The results of this search and review showed that:

- Previous testing of PFDs has not been directed toward determining reliability of PFDs. These tests have been concerned with evaluating specific designs or materials.

- Current test specifications used on PFDs are based on generalized test procedures and have not been adapted to PFD reliability.

2.0 COLLECTION AND ANALYSIS OF PFDS USED IN A RECREATIONAL BOATING ENVIRONMENT

2.1 Introduction

In order to develop an accelerated aging methodology that will produce useful and meaningful results, it is necessary to evaluate PFDs that have been used by recreational boaters. The analysis of "used" PFDs provides a criteria on which to base the development of the accelerated aging procedures.

2.2 Selection of Criteria for Use in Collecting Used PFDs

The main purpose for the collection of used PFDs and their respective histories is to provide both qualitative and quantitative information on the degradation of PFDs used in recreational boating. Due to the fact that there is such a large variety of PFDs in use by boaters, the collection of PFDs requires more than a random sampling process. Several factors need to be identified and/or controlled for in the selection/collection of used PFDs.

1) In order to identify the important stressors in PFD degradation, the results from the collection of used PFDs cannot be confounded by the collection of a wide variety of PFDs. Factors such as type of PFD, covering material, manufacturer of PFD, and type of flotation material, will all increase the variability of the results of used PFD collection These, therefore, must be controlled for if the effects of normal usage and environmental factors are to be isolated.

2) The reliability of PFDs used by recreational boaters is affected to a large extent by the type of exposure the PFD receives. Some factors determining PFD exposure, thus PFD reliability, would be:

   - amount of boating
   - main boating activity
   - type of PFD storage and maintenance
   - area of country

These stressors and PFD exposure factors are graphically shown in Figure V(A)-1.

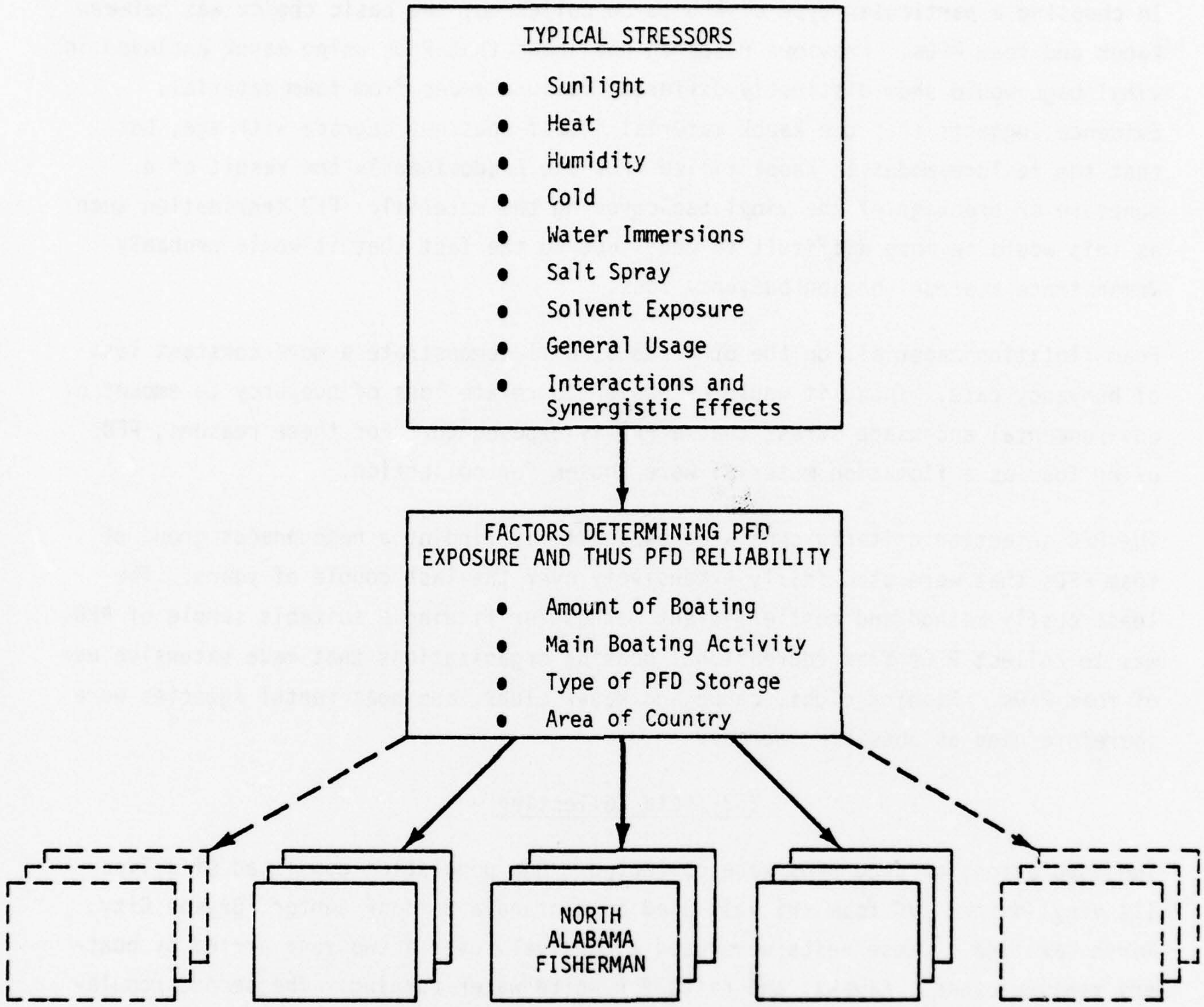


FIGURE V(A)-1. EXPOSURE FACTORS DETERMINING PFD RELIABILITY

In choosing a particular type of PFD to be collected, the basic choice was between kapok and foam PFDs. Previous research had shown that PFDs using kapok enclosed in vinyl bags would show distinctly different failure modes from foam material. Evidence suggests that the kapok material itself does not degrade with age, but that the failure modes in kapok filled PFDs are predominantly the result of a puncture or breakage of the vinyl bag covering the material. PFD degradation such as this would be more difficult to model due to the fact that it would probably demonstrate a step-function buoyancy loss.

Foam flotation material, on the other hand, will demonstrate a more constant loss of buoyancy rate. Thus, it would be easier to relate loss of buoyancy to amount of environmental and usage stress that a PFD is exposed to. For these reasons, PFDs using foam as a flotation material were chosen for collection.

The PFD selection criteria consisted basically of finding a homogeneous group of foam PFDs that were used fairly extensively over the last couple of years. The least costly method and most efficient method for finding a suitable sample of PFDs was to collect PFDs from recreational boating organizations that made extensive use of foam PFDs. Fishing clubs, canoe and kayak clubs, and boat rental agencies were therefore used as possible sources.

2.3 Data Collection

Two populations of used PFDs were collected. One population consisted of a Type III vinyl-dipped PVC foam ski vest used by Nantahala Outdoor Center, Bryson City, North Carolina. These vests were used extensively over a two year period by boaters renting canoes, kayaks, and rafts for white water running. The second population consisted of a Type III cloth and mesh covered PVC foam PFD. This population contained a wider variety of styles of vests such as canoe/kayak and hunter/fisherman and were collected from individual owners throughout North Alabama (see Figures V(A)-2 and V(A)-3).

An environmental profile data sheet was designed for the collection of information on the used PFDs. The main purpose of the environmental profiles was to:

- provide an overall picture of the type and amount of usage and environmental stress to which PFDs are normally exposed;

FIGURE V(A)-2. TYPE III VINYL DIPPED PVC FOAM SKI VEST

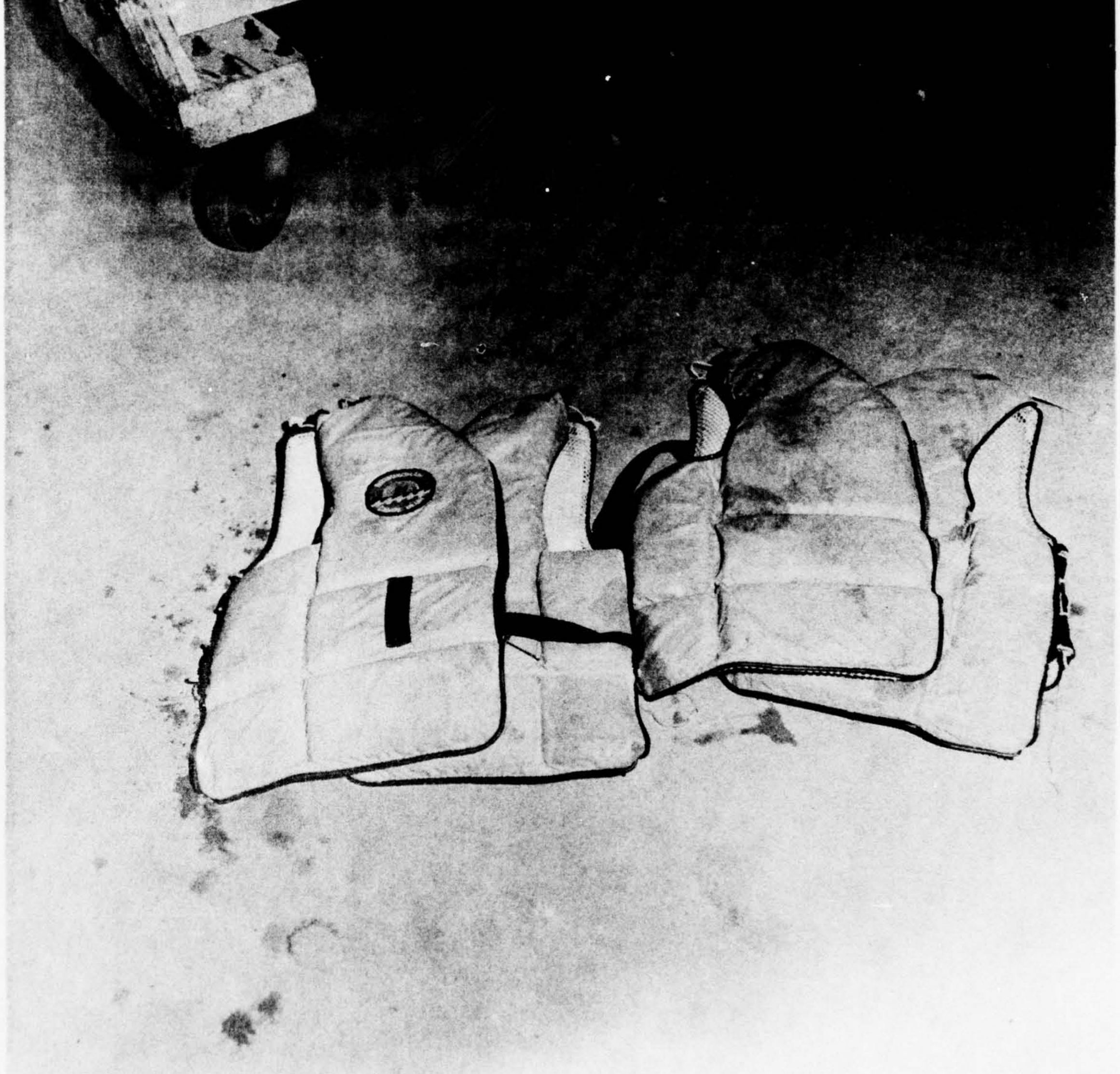


FIGURE V(A)-3. TYPE III NYLON AND MESH COVERED PVC FOAM PFD

- provide a quantitative and qualitative estimate of the stressors affecting PFD reliability and attempt to estimate which stressors are most important in PFD reliability.

- identify any abnormal or extreme conditions that might have contributed to degradation.

The factors identified in the data sheets were:

- type of boating activity PFD normally used in
- amount of usage PFD received
- severity of usage received (i.e., constant wearing, sitting on, etc.)
- storage location of PFD when not used and the extremes exposed to
- type and amount of extreme environmental exposure.

2.4 Data Analysis - North Alabama PFDs

Upon examination of a number of alternative plans, the collection of PFDs used by boaters in North Alabama was found to be the most advantageous for the following reasons:

- According to available statistics (Nationwide Boating Survey), this area of the country had a higher amount of boating exposure than any other area of the country.

- The availability of a large number of recreational boating organizations such as bass clubs provided ease of access to groups using Type III foam PFDs.

- Due to the logistics problems involved in collecting PFDs in other areas of the country, this area was attractive from a cost standpoint.

Information was gathered from the boating groups on age and type of PFD available and from this, a random sample of the desired PFDs was selected.

A total of 25 PFDs were collected from boaters throughout North Alabama. Of this sample 20 were used by boaters whose principal activity was fishing/cruising, and the remaining five were principally canoe/kayak enthusiasts.

An overall picture of the type of usage and environmental stress that the 25 PFDs were exposed to was assembled from the individual environmental profiles collected for each PFD. Table V(A)-1 provides a summary of the environmental profiles and the relevant environmental conditions that existed for these PFDs. The table shows the estimated mean and standard deviation for the number of days of usage for the PFD per month. An examination of the estimated average length of outing for individual cases showed very little difference existing month to month; therefore an overall mean length of outing was derived. The mean length of outing for these particular boaters was 7.4 hrs with a standard deviation of 2.8 hrs. An analysis of the type of storage revealed that most boaters preferred to provide some type of protection for their PFD. Nineteen of the boaters provided protection such as leaving PFDs in their garage, storing PFDs in dry well of boat or under bow of boat, etc. The remaining six boaters stored their PFDs in the closet of a house or some place that was not exposed to any environmental extremes. Most of these vests were subjected to fairly heavy usage such as being worn most of the time or being sat upon. Very rarely would someone leave a vest of this type stored when out boating. PFDs that were used by canoe/kayak enthusiasts were exposed to a much larger number of wetting and drying cycles than those used by the fishermen.

Based on the information from the environmental profiles, the two independent variables of age in years and days of usage for each PFD were derived. The degree of relationship between these two variables was determined by plotting the boater's estimate of days of usage versus his estimate of years of usage for each PFD (see Figure V(A)-4). A least squares regression line is fit to the data to provide a prediction equation for estimating the number of days of usage based on the age of the PFD in years ($r = 0.57$, $p < 0.01$). This equation predicts that on the average this sample of recreational boaters would be boating almost 61 days per year.

The 25 PFDs collected were evaluated on three criteria: 1) functional nature of the closure mechanism (in this case zippers), 2) condition of the covering material and supporting stitching, and 3) amount of buoyancy provided by PFDs.

An evaluation of the PFDs based on criteria 1 and 2 showed that most PFDs showed very little deterioration with usage. All zippers except for two showed no signs of being unusable. Of the two zippers that were faulty, one showed a complete

TABLE V(A)-1. SUMMARY OF ENVIRONMENTAL PROFILES

MONTH	MEAN AND STANDARD DEVIATION OF ESTIMATED DAYS OF USAGE OF PFD PER MONTH		ENVIRONMENTAL CONDITIONS**					
	MEAN	STANDARD DEVIATION	MEAN NUMBER OF DAYS RAIN* PER MONTH	SUNSHINE - MEAN NUMBER OF DAYS: CLEAR	PARTLY CLOUDY	CLOUDY	TEMPERATURE RANGE IN °F	HUMIDITY RANGE IN PERCENT RELATIVE HUMIDITY
JANUARY	3.0	3.1	13	7	5	19	50-31°	84-69
FEBRUARY	3.8	2.8	10	7	6	15	54-33°	82-62
MARCH	5.9	4.2	12	7	8	16	62-40°	83-59
APRIL	6.3	3.9	9	10	6	14	73-50°	81-53
MAY	6.6	3.6	11	10	10	11	81-58°	88-58
JUNE	6.2	3.7	10	9	11	10	88-66°	88-57
JULY	6.3	3.8	12	7	13	11	90-69°	89-62
AUGUST	5.9	3.8	9	10	13	8	90-68°	89-60
SEPTEMBER	5.4	4.2	9	8	10	12	84-62°	90-62
OCTOBER	5.2	4.3	7	12	8	11	75-50°	87-58
NOVEMBER	3.4	3.2	9	10	6	14	62-39°	85-59
DECEMBER	3.0	3.1	12	8	4	19	52-37°	83-66
TOTALS	61.0 DAYS EXPOSURE							

	TYPE OF STORAGE FOR PFD		
	DIRECT	INDIRECT	NON-EXPOSURE
NUMBER OF BOATERS	0	17	6

AVERAGE LENGTH OF OUTING = 7.4 hr.
STANDARD DEVIATION = 2.8 hr.

* 0.01 inch or more

** Taken from local climatological data, National Climatic Center, Asheville, N. C. for Huntsville, Alabama

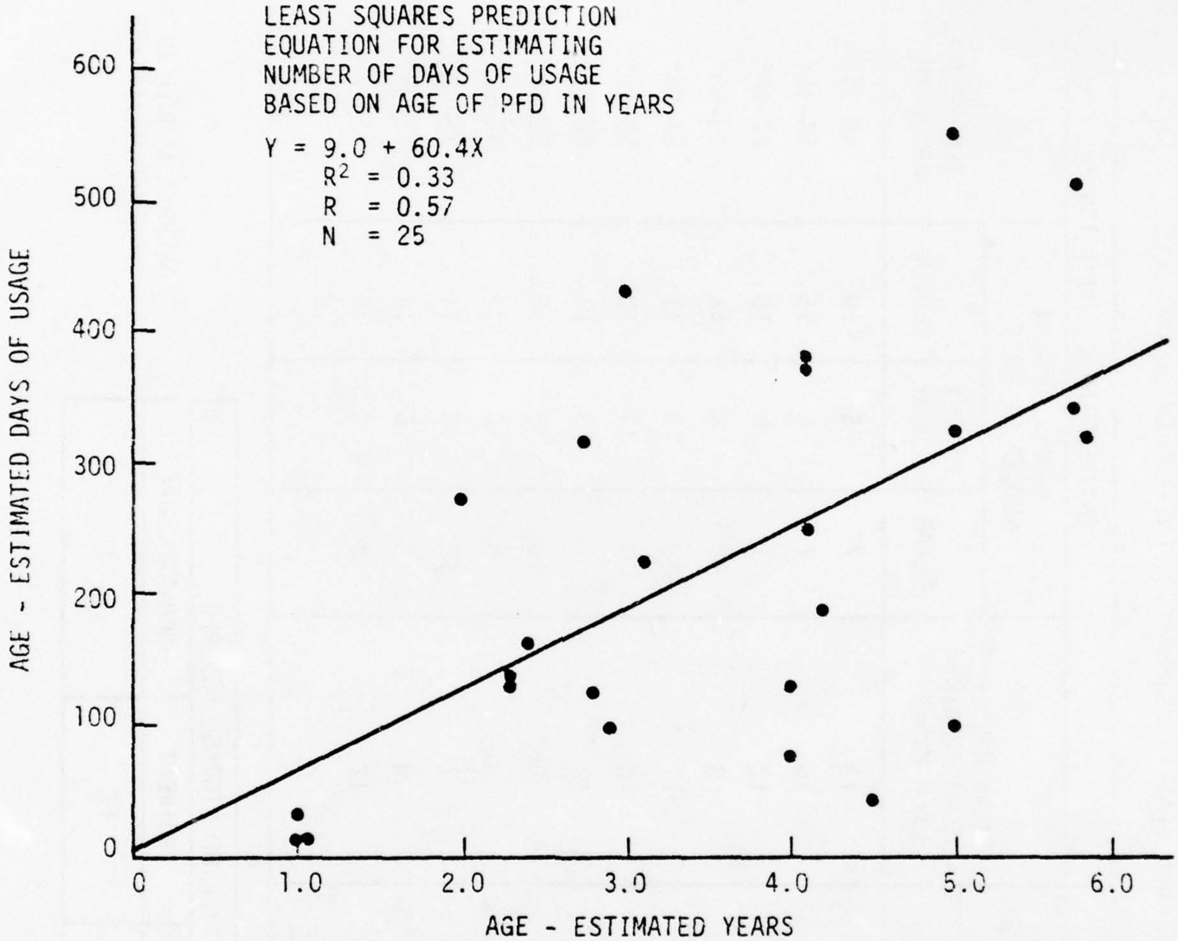


FIGURE V(A)-4. PLOT OF ESTIMATED AGE IN YEARS AGAINST ESTIMATED DAYS OF USAGE FOR PFDS USED BY RECREATIONAL BOATERS IN NORTH ALABAMA

breakdown of the zipper mechanism and the other one had been partially torn from the jacket but was still functional. These zippers were also tested to determine whether corrosion or aging had affected the force required to operate the zipper. The used zippers and a sample of new zippers were tested for the force required to close the zipper once started. This is commonly known as an operability force test. No difference was found between the sample of used PFDs and a sample of new PFDs with the average force being 2.0 lbs. Apparently, the usage environment to which these PFDs had been exposed did not lead to noticeable corrosion in the zipper. This environment did not contain salt-water exposure. The effect of salt-water exposure on zipper operability was examined in Section 3.4.

A visual inspection of the covering material and stitching of the jackets showed that all were very sound except for the oldest jacket where the fabric had worn through in one spot producing a hole approximately two inches long and one-half inch wide. This did not appear to affect the functional capability of the PFD. In order to determine, however, the degree to which the PFD structure had deteriorated, PFDs were evaluated for overall strength capability. PFDs were put under increasing weight stress until a total breakdown of some part of the PFD structure was seen. In order to determine the effects of aging on PFD structure, a sample of used PFDs between 4 and 6 years old were tested and compared to a sample of new PFDs. The results showed that there was no statistical difference between the strength of the used PFDs and new PFDs ($t = 0.6$, $p > 0.8$). The average reading for these PFDs was 455 lbs at breaking strength. The failure mode was one of the following three: 1) zipper was torn from lining, 2) zipper teeth were torn apart, 3) cloth torn away from sewn part. The fabric material does not appear to be degrading for these PFDs and the weakest link for both new and used PFDs is either at or near the zipper (see Figure V(A)-5).

The most important criteria for use in evaluating the reliability of the PFD is the buoyancy provided. All 25 PFDs were submerged in fresh water for 24 hours and buoyancy measurements taken.

In order to obtain an accurate indication of the buoyancy loss for these PFDs, estimates of the initial buoyancies are needed. Due to the fact that the initial buoyancies of the PFDs varied among size and model, estimates of the initial buoyancy for each PFD were made by obtaining manufacturer's measurements of appropriate size/model sample lots. These estimated lot buoyancies were obtained through the

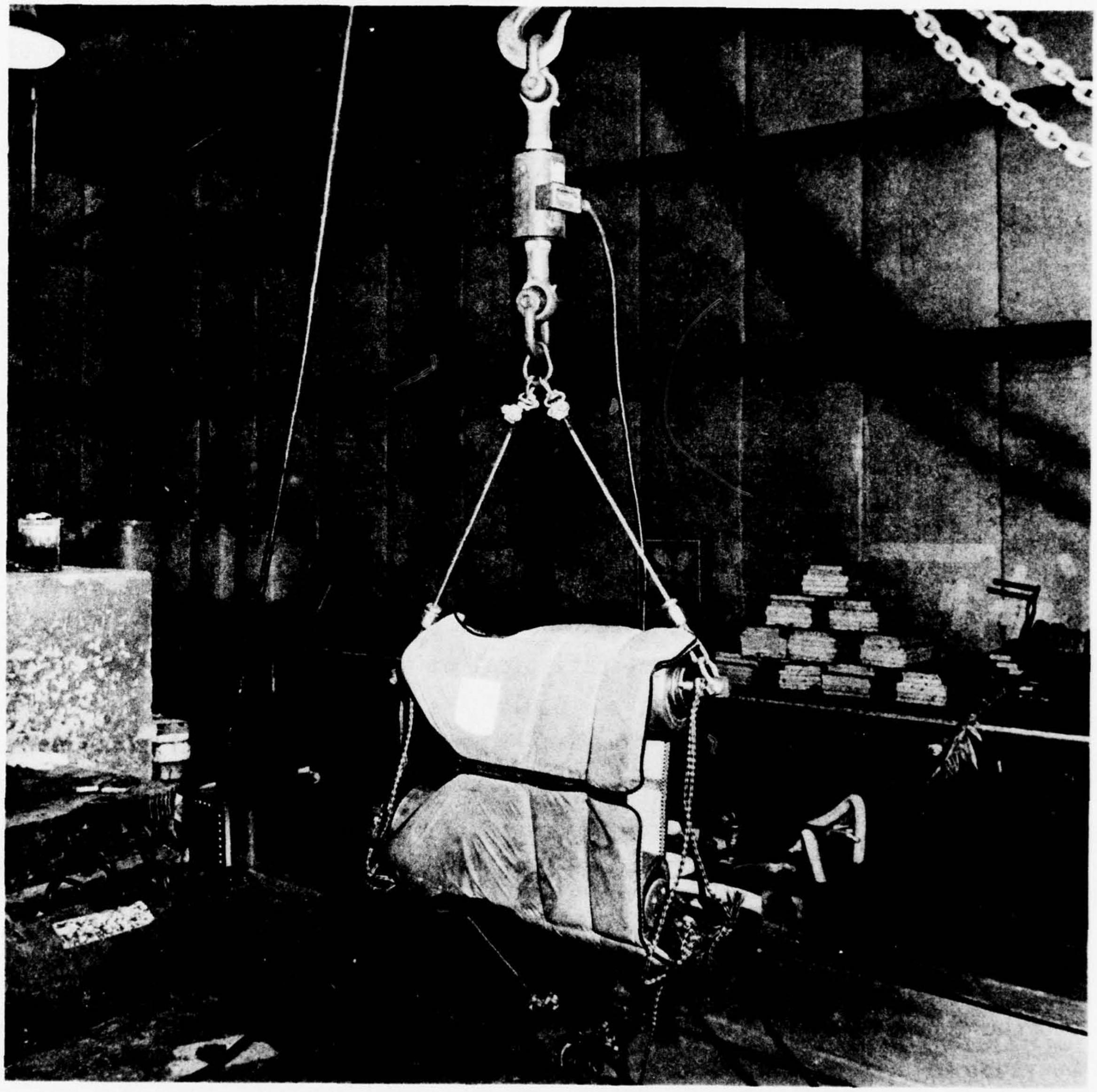


FIGURE V(A)-5. PFD TENSILE STRENGTH TEST

Coast Guard Office of Merchant Marine Safety. Using these estimates of initial buoyancy and current buoyancy, an estimated buoyancy loss for each PFD was obtained.

Initially, it is of interest to determine whether any significant difference exists between loss of buoyancy for PFDs owned by conoeists/kayakers and fishermen. The null hypothesis of no significant difference in buoyancy loss between the two groups was tested by determining the mean buoyancy loss for the five canoe/kayak vests and for nine fishermen/cruising vests of similar ages. A t-test for differences in means was performed and no significant difference was found ($t = 0.83$, $df = 12$, $p > 0.2$). Since no significant difference was found between the fishermen vests and canoe/kayak vests, these two samples were combined to obtain one sample group of 25 PFDs.

Figure V(A)-6 shows a plot of the buoyancy loss for each of the 25 used PFDs collected vs. the estimated age of each PFD in years. A least squares linear regression curve was fit to this data to provide an estimate of the average loss of buoyancy over time for these PFDs ($r = 0.67$, $p < 0.01$). A loss of buoyancy of 0.65 lbs over a one year period is predicted by this data. A 90% and a 95% upper limit confidence intervals have also been calculated for this data. This confidence interval points out that only 10% and 5%, respectively, of any sample collected will have lost more buoyancy than this upper limit. For instance, at three years old, no more than 10% of the PFDs sampled will have lost more than 3.2 lbs.

Figure V(A)-7 shows a plot of the same data for estimated percentage loss of buoyancy from new vs. estimated age of PFD in years. The estimated percentage loss of buoyancy was derived by taking the buoyancy loss from new and dividing it by the estimated buoyancy when new. Again, a least squares linear regression line was fit to the data to provide an estimate of the average percentage loss in buoyancy ($r = 0.64$, $p < 0.01$). An average of 3.3% buoyancy loss from new is predicted for each year. The 90% and 95% upper confidence intervals have also been calculated for this graph.

A plot of the other available independent variables such as days of usage and hours of usage was made against buoyancy loss. The results revealed that neither of these independent variables would provide a better predictor of buoyancy loss than the age of the PFD in years. This was probably due to the inability of the boaters to provide accurate and reliable estimates of the amount of boating they do.

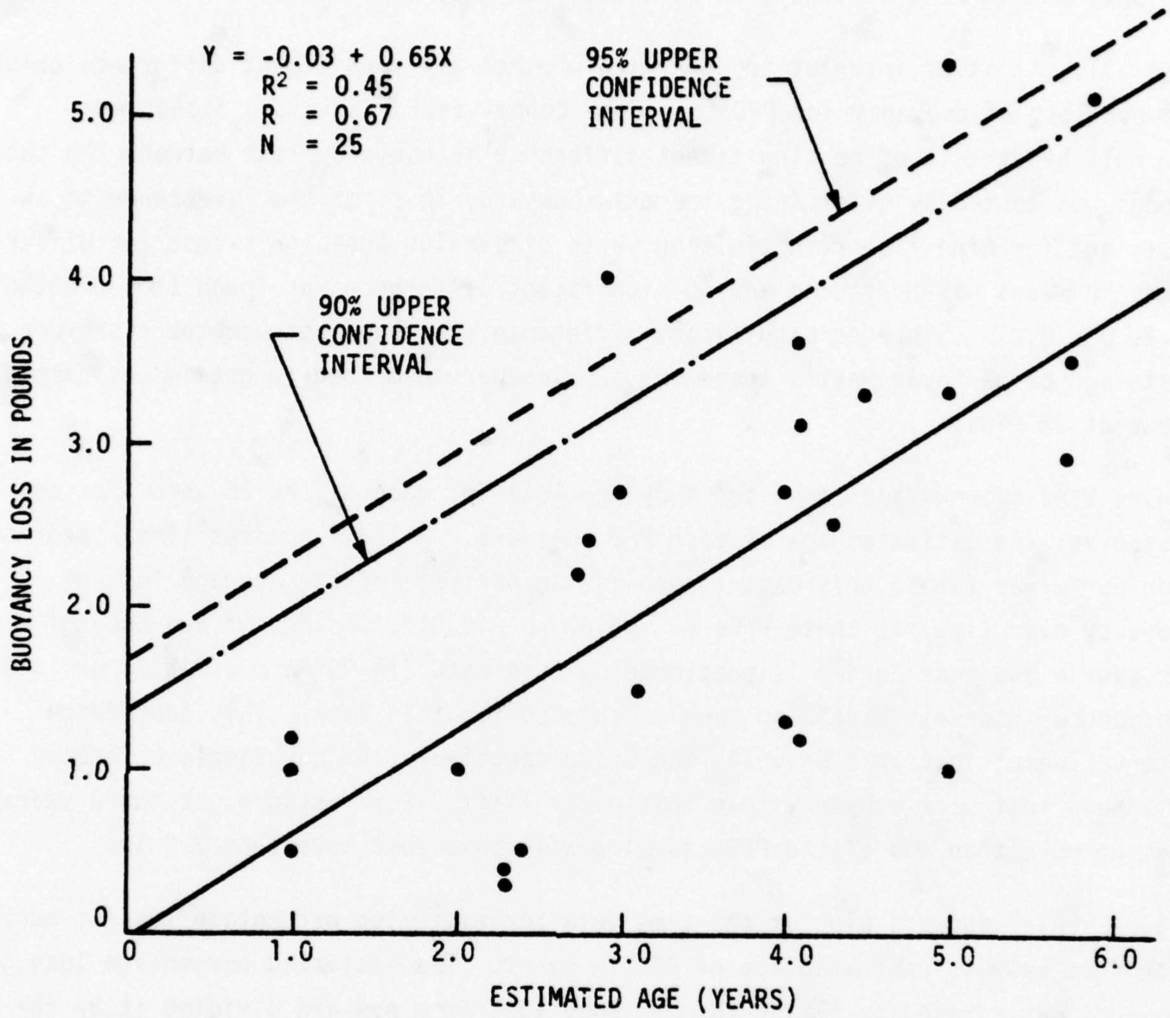


FIGURE V(A)-6. PLOT OF AGE OF PFD VS. POUNDS OF BUOYANCY LOST FOR PFDS COLLECTED IN NORTH ALABAMA

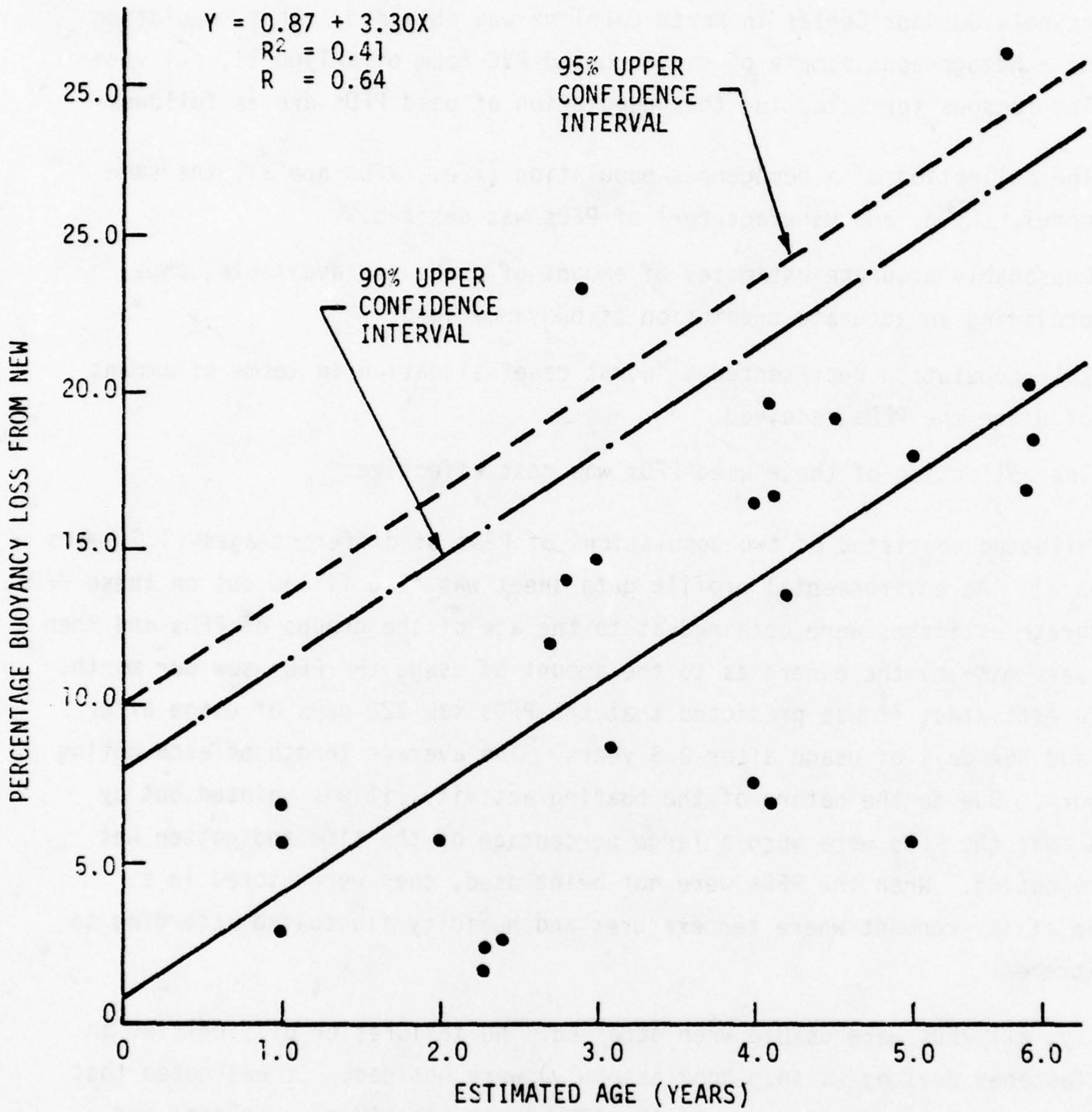


FIGURE V(A)-7. PLOT OF AGE OF PFD VS. PERCENTAGE BUOYANCY LOSS FROM NEW FOR PFDS COLLECTED IN NORTH ALABAMA

2.5 Data Analysis - North Carolina PFDs

In addition to the collection of PFDs used in North Alabama, a population of PFDs used by Nantahala Outdoor Center in North Carolina was obtained. This population consisted of a homogeneous sample of vinyl coated PVC foam of a Type III ski vest variety. The reasons for selecting this population of used PFDs are as follows:

- The collection of a homogenous population (i.e., PFDs are all the same model, style, and manufacturer) of PFDs was desired.
- Reasonably accurate estimates of amount of usage are available, thus providing an accurate prediction of buoyancy loss.
- This population represented a "worst case" situation in terms of amount of usage the PFDs received.
- The collection of these used PFDs was cost effective.

The PFDs collected consisted of two populations of PFDs of different ages (1.6 years and 2.6 years). An environmental profile data sheet was also filled out on these PFDs. Fairly accurate estimates were obtained as to the age of the groups of PFDs and then estimates were made by the owners as to the amount of usage the PFDs saw per month. Using these estimates, it was predicted that the PFDs saw 220 days of usage after 1.6 years and 367 days of usage after 2.6 years. The average length of each outing was 5.0 hours. Due to the nature of the boating activity, it was pointed out by the owners that the PFDs were worn a large percentage of the time and gotten wet about every outing. When the PFDs were not being used, they were stored in a garage type of environment where temperatures and humidity fluctuated according to outdoor extremes.

Structurally, all PFDs were usable when obtained. No failures or difficulties in using the fastener devices (a snap hook assembly) were noticed. It was noted that excessive wear was occurring to many of the PFDs in the shoulder strap area and that the owner had used tape to reinforce this area. A sample of these PFDs were also tested on the tensile strength machine for overall structural strength. The PFDs were tested for a pass/fail criteria of 300 lb for a five minute duration. Four out of five of the PFDs could support this weight for a five minute period.

An estimate of the initial buoyancy of these PFDs was made using Coast Guard data on measurements of new sampled lots. A single estimate of initial buoyancy was derived by averaging the estimates of the initial lot buoyancies. No estimate of variance was available.

Buoyancy measurements were made of each of the two populations at the different ages. Figure V(A)-8 shows a plot of the two populations and initial buoyancy estimate vs. the estimated number of days of usage and the estimated number of years of usage. The results show that the average buoyancy after 1.6 years of usage or 220 days of usage was 13.5 lb and after 2.6 years of usage or 367 days was 13.2 lb.

2.6 Comparison Between the Two Populations

Before any comparison between these two populations can be made, the major differences must be noted.

1. The North Carolina PFDs used a vinyl dipped covering while the North Alabama PFDs were cloth and mesh-covered.
2. North Carolina PFDs represent a worst case situation in terms of the amount of usage seen over a period of time.
3. The PFDs in North Carolina were used under possibly different conditions (i.e., area of the country) from those collected in North Alabama.
4. The PFDs were from different manufacturers.

An initial comparison of the loss of buoyancy for the two populations shows that the North Carolina PFDs lost much more buoyancy over a 2.6 year period than the North Alabama PFDs. If, however, a comparison in buoyancy loss between these two populations is made in terms of days of usage that the PFDs saw, this difference disappears (see Figure V(A)-9). The estimated buoyancy loss after 367 days of usage for 32 North Carolina PFDs was an average of 3.26 lbs. A group of nine North Alabama PFDs with an average of 393 days of usage were evaluated and found to have a mean buoyancy loss of 3.29 lbs. A comparison between the means and standard deviations of buoyancy loss of the two populations was made. An F-test for comparison of two sample variances was made and showed a statistically significant difference ($F = 1.88$, $p < 0.10$). This difference can be attributed to the large variation in type of usage and storage that PFDs in North Alabama were exposed to. A t-test for comparison of means was made in order to determine whether differences in

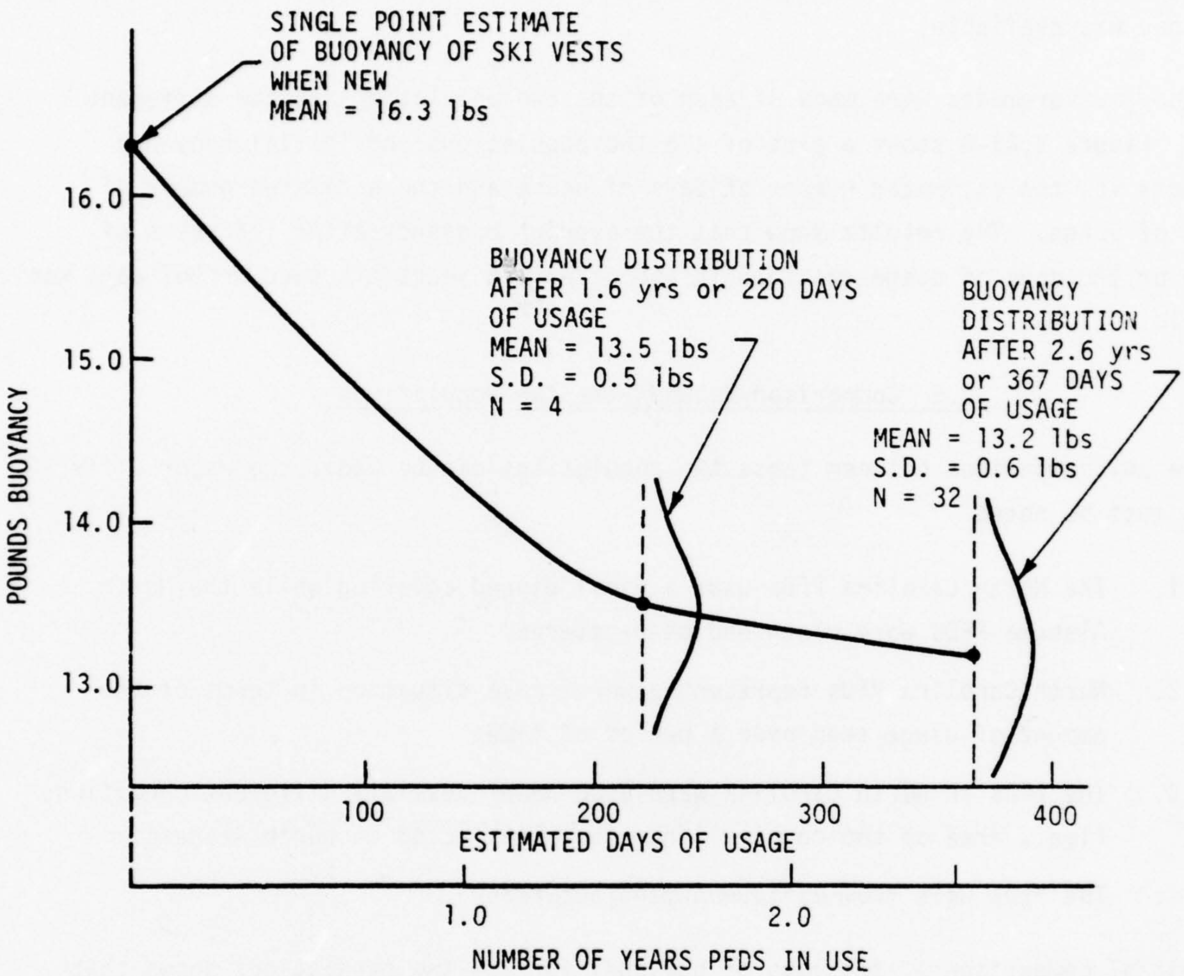


FIGURE V(A)-8. BUOYANCY DISTRIBUTIONS FOR VINYL DIPPED PVC FOAM PFD USED BY BOATERS IN NORTH CAROLINA

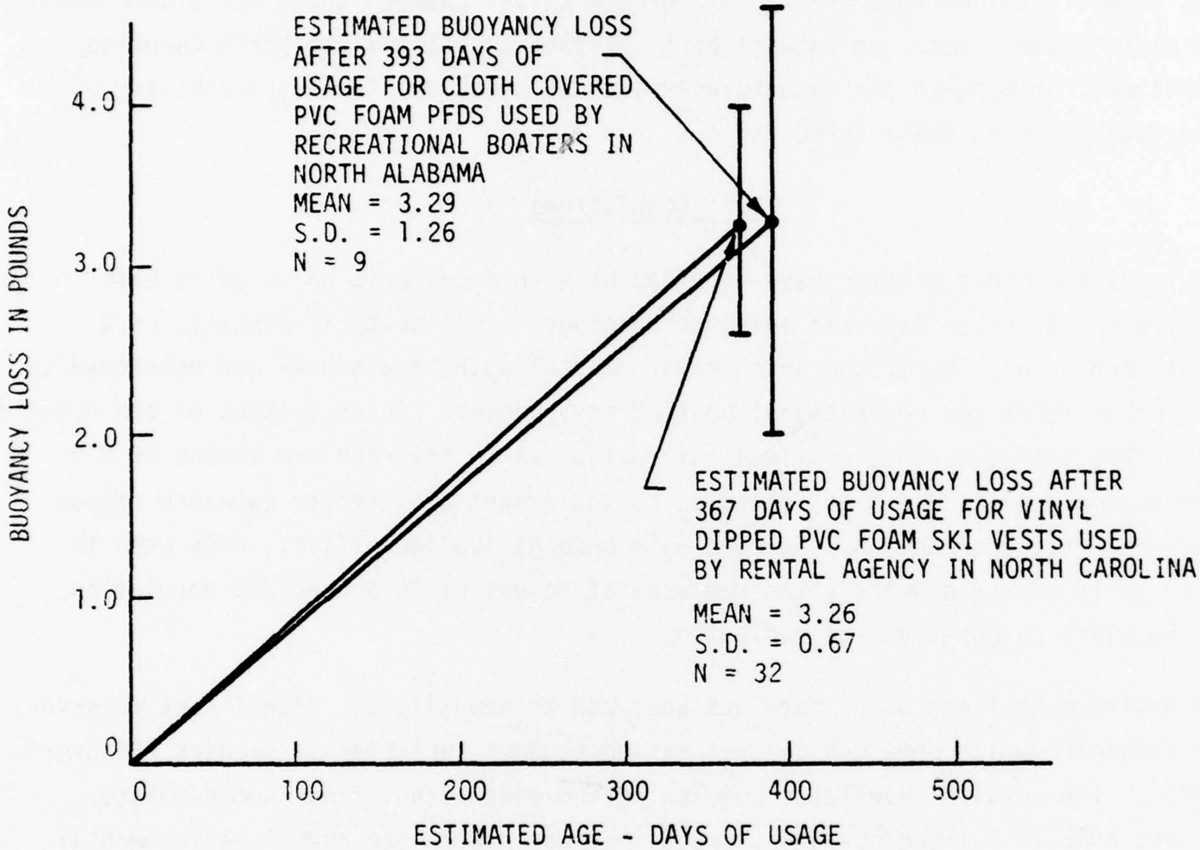


FIGURE V(A)-9. COMPARISON OF BUOYANCY LOSS FOR THE TWO POPULATIONS OF USED PFDS COLLECTED

mean buoyancy loss between the two groups existed ($t = 0.14$, $p > 0.75$). No statistically significant difference in mean buoyancy was found. This result suggests that no difference in reliability between the vinyl dipped vests used in North Carolina and the cloth covered vests used in North Alabama exists. It is impossible, however, to conclude that no difference exists between the vinyl dipped foam and cloth covered foam, or between North Alabama conditions and North Carolina conditions, or between one manufacturer and the other due to the possibility of interactions among these three factors.

2.7 Conclusions

The results of this section have provided us with a criteria on which to base the development of an accelerated aging methodology. This criteria consists of a population(s) of PFDs around which environmental aging procedures are developed to reflect or model the recreational boating environment. An evaluation of the results of the PFD collection has provided information as to the rate and amount of PFD degradation over time and estimates as to the amount of stressor exposure responsible for this degradation. As more data becomes available (i.e., PFDs used in other parts of the country), the representativeness of this used PFD population for modeling purposes can be evaluated.

The environmental and usage data was analyzed to identify the significant stressors and determine which ones can be used as independent variables to predict PFD degradation. The results revealed a complex environment with various human-related factors such as maintenance and storage interwoven with the normal environmental stressors. Therefore, for the most part, the separation and identification of the significant stressors was not possible with the PFDs collected. A series of individual stressor experiments was found necessary in order to be able to identify the significant stressors. The results from the individual stressor experiments in combination with the results from this section on PFD degradation predictors such as age and amount of usage provide the tools necessary for development of the accelerated aging and reliability test procedures.

In the development of the accelerated aging procedures to model the boating environment, it is necessary to choose one of the populations for use in comparison with the accelerated aged population. Due to the fact that 1) the type of vests used in

North Carolina are no longer manufactured, and 2) the PFDs used in North Alabama are more representative of normal boating, the decision was made to use the North Alabama population for modeling purposes.

The results from the collection of the PFDs used by the boat rental agency in North Carolina show that the severity of usage over a given period of time was much greater than with those used by "normal" boaters in North Alabama. This suggests that the PFDs used by boat rental agencies where severe usage is expected will have a shorter useful life. PFD reliability requirements should reflect this fact in requiring either more severe reliability testing or a specified shorter useful life for the PFD.

3.0 INDIVIDUAL OVERSTRESS EXPERIMENTS

3.1 Introduction and Purpose

In the development of an accelerated aging methodology, a major problem is the determination of which of the stressors is contributing to the degradation of the PFD, and to what extent each is affecting the PFD. The collection and analysis of PFDs used by recreational boaters has provided information as to the overall environmental and usage stresses that PFDs are exposed to. Due to the large number of stresses and wide variety of PFDs in use, it is difficult to isolate the effect of any one stressor or combination of stressors. Therefore, controlled experiments are designed in order to identify which of the stressors is contributing most to PFD degradation and which appear to be inconsequential to the degradation process. In addition to discovering which stressors are important, the effects of overstress experiments and the determination of the range in which accelerated stressors may be used is needed. One of the main constraints of an accelerated aging process is that the stressors used in accelerating the aging must be kept within some predetermined range in order to assure that the failure modes will be the same in accelerated as in natural aging. Figure V(A)-10 shows a conceptulization of the effects of various stressor intensities on life length.

In addition, an optimal operating range for the accelerated stressors needs to be examined. A determination of whether any relationships exist between higher level of stressor intensity and increased degradation would be of interest. Using information such as this, the most cost/time effective method for accelerating the aging process of PFDs can be designed (Figure V(A)-11).

Based on an analysis of the recreational boating environment, the following list of possible stressors was derived.

- Sunlight
- Heat
- Humidity
- Salt Spray
- Cold
- Heat/Cold Cycling
- Water Soakings
- General Usage
- Solvent Exposure

The results from the individual stressor experiments follow.

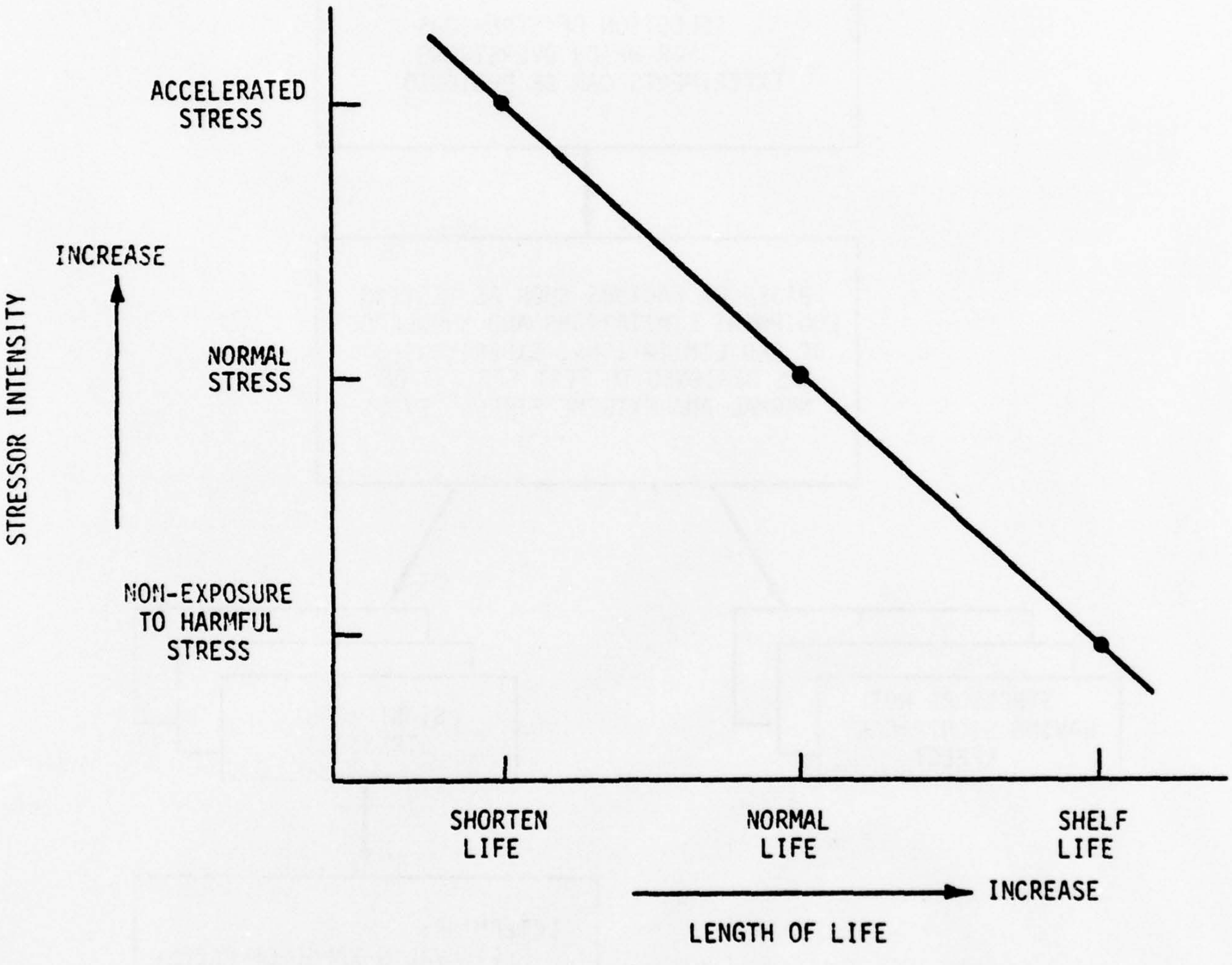


FIGURE V(A)-10. THEORETICAL EFFECTS OF STRESSOR INTENSITY ON LIFE LENGTH

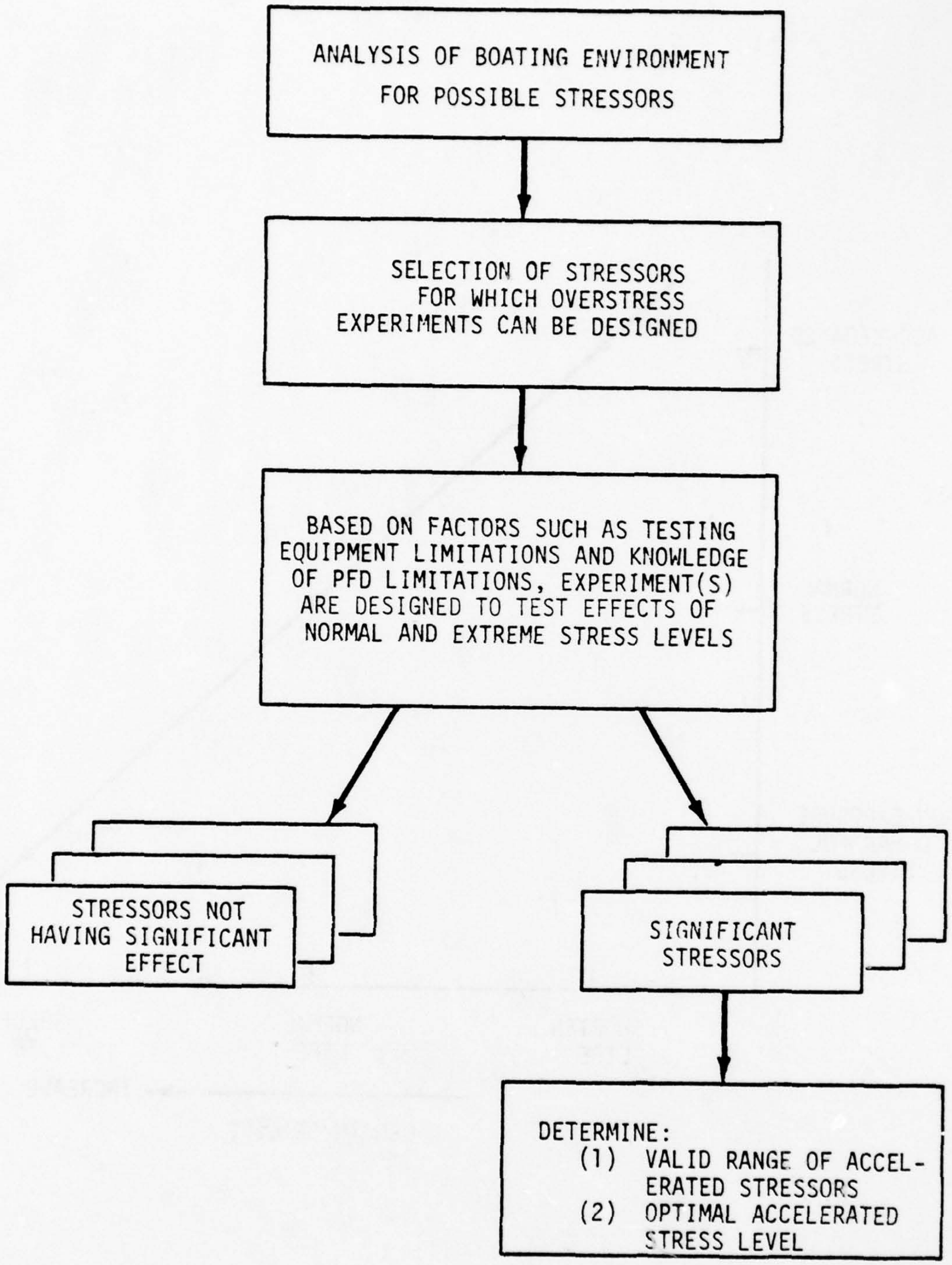


FIGURE V(A)-11. THE ROLE OF INDIVIDUAL OVERSTRESS EXPERIMENTS IN DEVELOPING THE ACCELERATED AGING SEQUENCE

3.2 Sunshine Experiments

3.2.1 Procedure

Due to the nature of the activity in which PFDs are used, one of the most important of the environmental stressors that needs to be examined is sunlight. Earlier research (Appendix V(A)-A) has indicated that some foam materials are susceptible to degradation due to sunlight exposure. This degradation could be the result of exposure to either the ultraviolet (this is known as actinic degradation) or infrared portions of the solar spectrum or both.

In order to explore the effects of sunshine exposure, PFDs were exposed to three sunlight conditions:

1. natural sunlight
2. artificial sunlight at natural sunlight intensities
3. artificial sunlight at accelerated intensities

Measurements were taken of loss of buoyancy and any observable changes in the PFD structure noted. These three sunlight conditions were chosen in order to provide a comparison between the degradation in "natural" and "artificial" environments and to determine the maximum degradation possible under accelerated intensities.

3.2.2 Natural Sunshine Exposure

An outdoor exposure experiment was designed in order to determine the effects of continuous exposure of PFDs to normal environmental conditions encountered in North Alabama. Four new Type III PVC foam PFDs, using a cloth and mesh-net covering were selected for continuous environmental exposure. The PFDs were mounted to a specially designed rack that could be moved in order to track the sun across the sky during the day, and thus provide maximum sunlight exposure. Environmental conditions to which the PFDs were exposed was well documented and an accurate picture obtained as to the cumulative environmental stressors that these PFDs were exposed to (Table V(A)-2). PFDs were exposed during the months of April through July and measurements of buoyancy taken approximately every three weeks.

TABLE V(A)-2. PROFILE OF ENVIRONMENTAL STRESSORS TO WHICH PFDS WERE EXPOSED

EXPOSURE PERIOD - CUMULATIVE NUMBER OF DAYS OF EXPOSURE	TEMPERATURE RANGE		RAINFALL		SUNSHINE		
	AVERAGE MAXIMUM	AVERAGE MINIMUM	NUMBER OF DAYS OF RAINFALL > .01 IN	TOTAL INCHES	CLEAR	PARTLY CLOUDY	CLOUDY
21	77°F	57°F	9	3.4"	4	7	10
42	84°F	60°F	6	3.4"	8	8	5
63	88°F	64°F	7	2.2"	10	4	7
84	93°F	70°F	6	0.9"	8	8	5

Figure V(A)-12 shows the results from the buoyancy measurements plotted against the days of exposure to North Alabama environmental conditions. The buoyancy measurements shown in this graph are the result of averaging the buoyancy measurements for two PFDs with the inside mesh netting exposed continuously to the sun and two PFDs with the backside cloth covered area to the sun. A comparision between the two groups for mean buoyancy loss was made and a statistically significant difference was found ($t = 5.0$, $p < .025$). The PFDs that were left with the unprotected foam material toward the sun showed a higher rate of buoyancy loss than those that were left with cloth covered foam directed toward the sun.

In addition to the measurment of environmental conditions to which the PFD was exposed, measurements of the temperature inside a PFD were taken. Temperature measurements were taken under two conditions (1) during a day with cloudy sky conditions and ambient temperature at 80°F, (2) under clear, sunny skies and ambient temperature in the upper 80°s. Measurements were taken with both a Leed's potentiometer and with a standard mercury thermometer. Measurements were taken for the worst case situation and therefore the temperature probe was placed between the cloth of a dark colored PFD and the foam material. Under Condition 1, the temperature inside the PFD rose to 115°-120°F and under Condition 2 the temperature rose to 131°-137°F.

3.2.3 Artificial Sunshine Exposure

A second experiment was designed in order to determine the effects on PFD degradation of exposure to "artificial" sunlight conditions of similar intensity as those experienced in a natural environment. In order to do this, it was necessary to determine the capabilitiles for the artificial sunshine chamber to be used.

The solar room used to expose PFDs to artificial sunlight was a 10' x 10' x 10' room with white reflectant walls. Ventilation ducts were arranged so as to provide air flow over the test articles. The light source consisted of 60 300 watt/120 volt reflector flood lamps employing a tungsten filament made by General Electric mounted on one wall by the test chamber. PFDs were arranged on a movable exposure rack, so that the distance of the test articles from the lamps could be varied if desired.

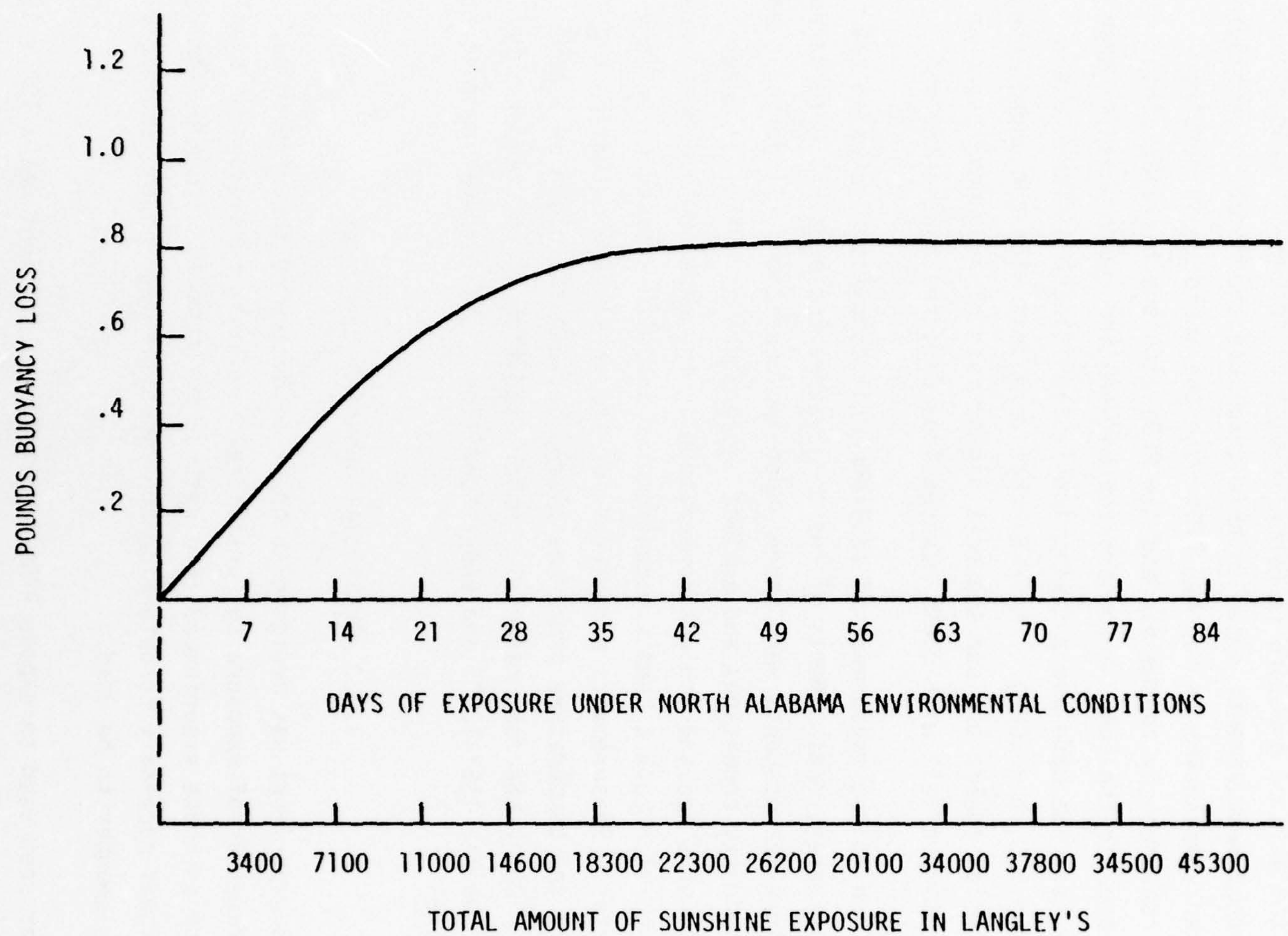


FIGURE V(A)-12. BUOYANCY LOSS FOR OUTDOOR EXPOSURE PFDS

Measurements of the sunshine chamber were taken using both a solar pyrheliometer to analyze the solar spectrum and a solar pyranometer to measure the total global insulation. Readings were taken at varying distances and intensities in order to discover the operable range of the test chamber. The results showed that these light arrangements provided similar ultraviolet intensity as that experience outdoors and therefore was capable of simulating natural sunshine in a general manner (see Figure V(A)-13).

Further testing was performed to determine whether the artificial solar radiation would exhibit the same characteristics under accelerated conditions as under normal intensities. The results showed that as the intensity of the artificial radiation was increased to accelerated levels both the total energy received (langleys) and the ultraviolet energy increased proportionately.

An additional factor that was recognized as important was the excess heat generated by the infrared solar energy. Due to the fact that this was an enclosed chamber with limited ventilation and accelerated solar intensities were being used, the buildup of excess heat could pose a problem. Therefore, based on the results of measuring PFD temperature under normal outdoor sunshine conditions, a representative temperature range was obtained. Testing was performed in the artificial sunshine chamber in order to determine the maximum intensity of the sunshine permissible for this temperature range.

Two extremes of the artificial sunlight environment were chosen for examination. One environment consisted of the light source at normal outdoor intensities with temperatures in a similar range and the other sunlight environment was set at the maximum range possible - twice the normal outdoor intensity and a higher temperature range. The exposure of a sample of new PFDs to these sunlight conditions was performed and measurements taken of the resultant loss of buoyancy. Figure V(A)-14 shows the buoyancy loss for each of the two conditions.

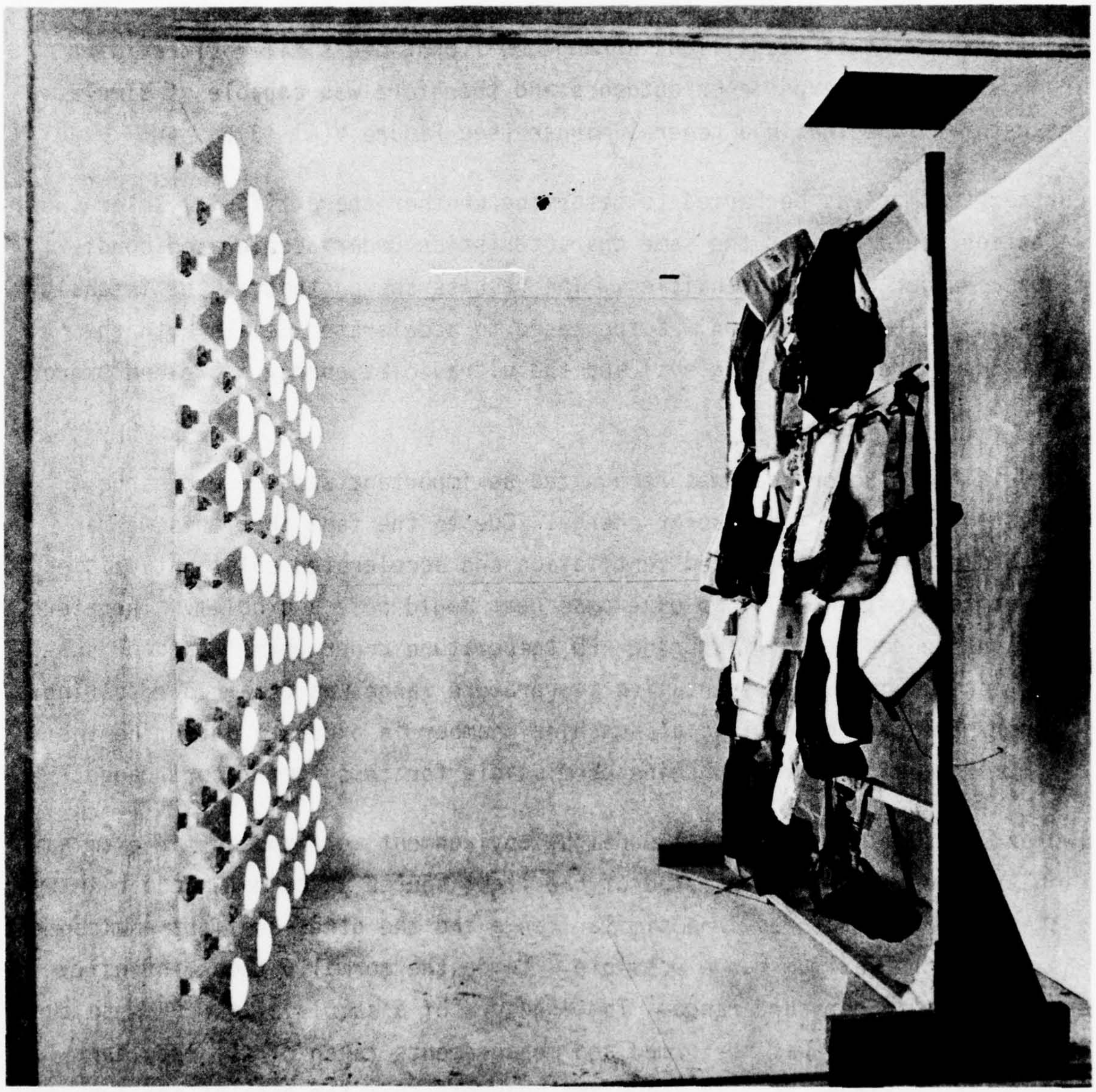


FIGURE V(A)-13. EXPOSURE OF PFDS TO ARTIFICIAL SUNSHINE

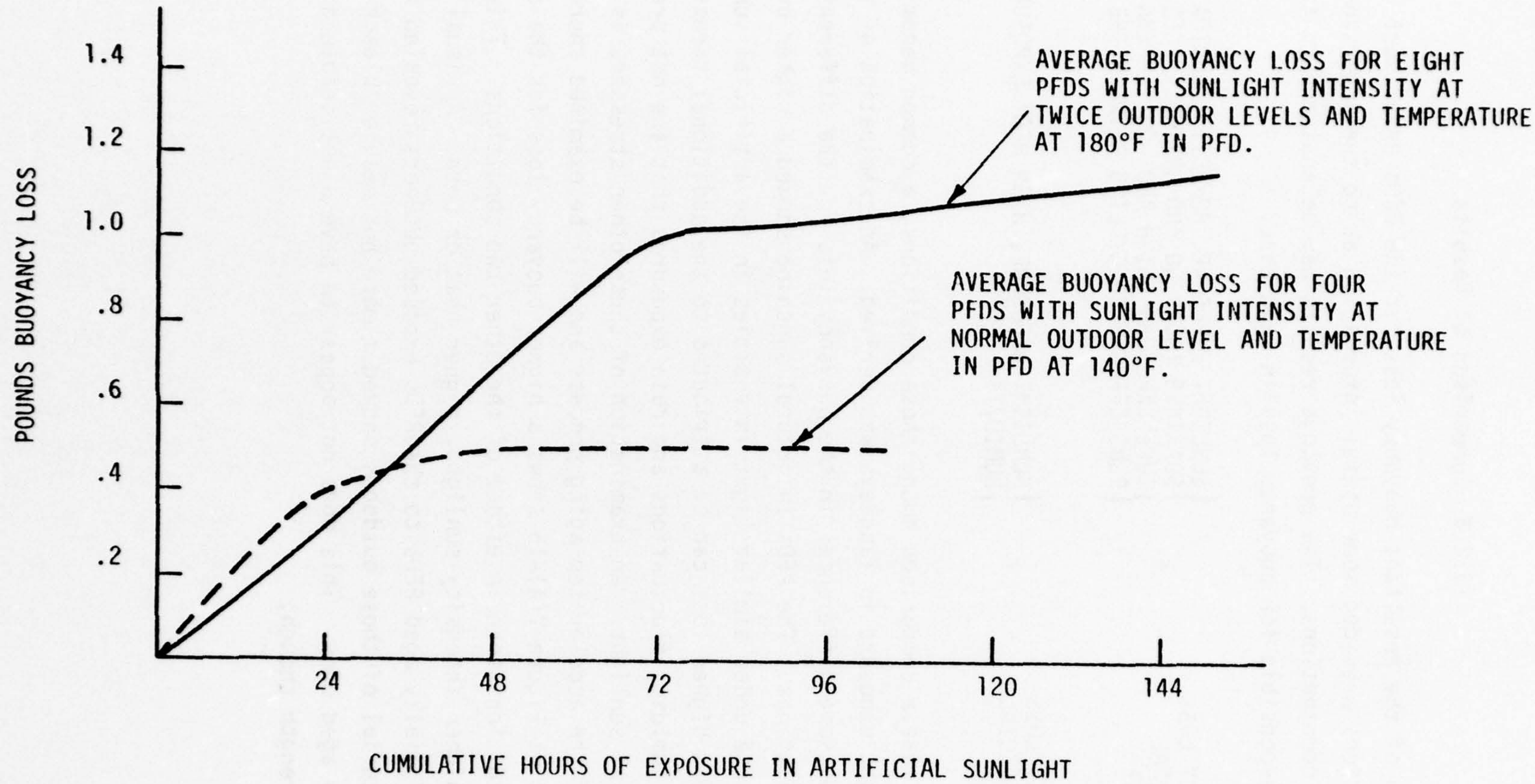


FIGURE V(A)-14. BUOYANCY LOSS FOR PFDS IN ARTIFICIAL SUNLIGHT

3.2.4 Comparison of Results

A comparison of the resultant buoyancy loss for the PFDs under each of the three conditions provided some useful information as to the important stressors or stressor combinations. The previous results can be analyzed in terms of the stressors responsible for buoyancy loss in each case.

BUOYANCY LOSS IN NATURAL SUNSHINE = f {SUNLIGHT EXPOSURE, HUMIDITY FLUCTUATIONS, RAIN SOAKINGS (SOAKING AND DRYING CYCLES), TEMPERATURE EXPOSURE (HIGH AND LOW TEMPERATURE EXPOSURE PLUS EFFECTS OF CYCLING BETWEEN THE TWO)}

BUOYANCY LOSS IN ARTIFICIAL SUNSHINE = f {SUNLIGHT EXPOSURE, HIGH HEAT EXPOSURE, LOW HUMIDITY}

In order to make a comparison among these conditions, a common denominator of total sunlight exposure in langleys was derived. An examination of Figure V(A)-15 shows some differences in the buoyancy loss for the different sunlight exposure conditions. The PFDs in natural sunshine showed a higher buoyancy loss than those under similar light intensities in the artificial sunlight chamber. This higher loss can be attributed to the additional stressors such as heat and humidity fluctuations and rain exposures that are not present under the artificial sunlight. An examination of these other stressors is an important part of the accelerated aging process and will be examined shortly. A further look at Figure V(A)-15 shows a higher buoyancy loss for the accelerated sunlight conditions than in either of the other two conditions. This is due to either the higher intensity sunlight, higher heat or both. A visual comparison of the artificially aged PFDs to the PFDs exposed outdoors revealed that the covering material of those outdoors showed a more noticeable "bleaching" than artificially aged ones. This does not appear to have a noticeable effect on material strength though.

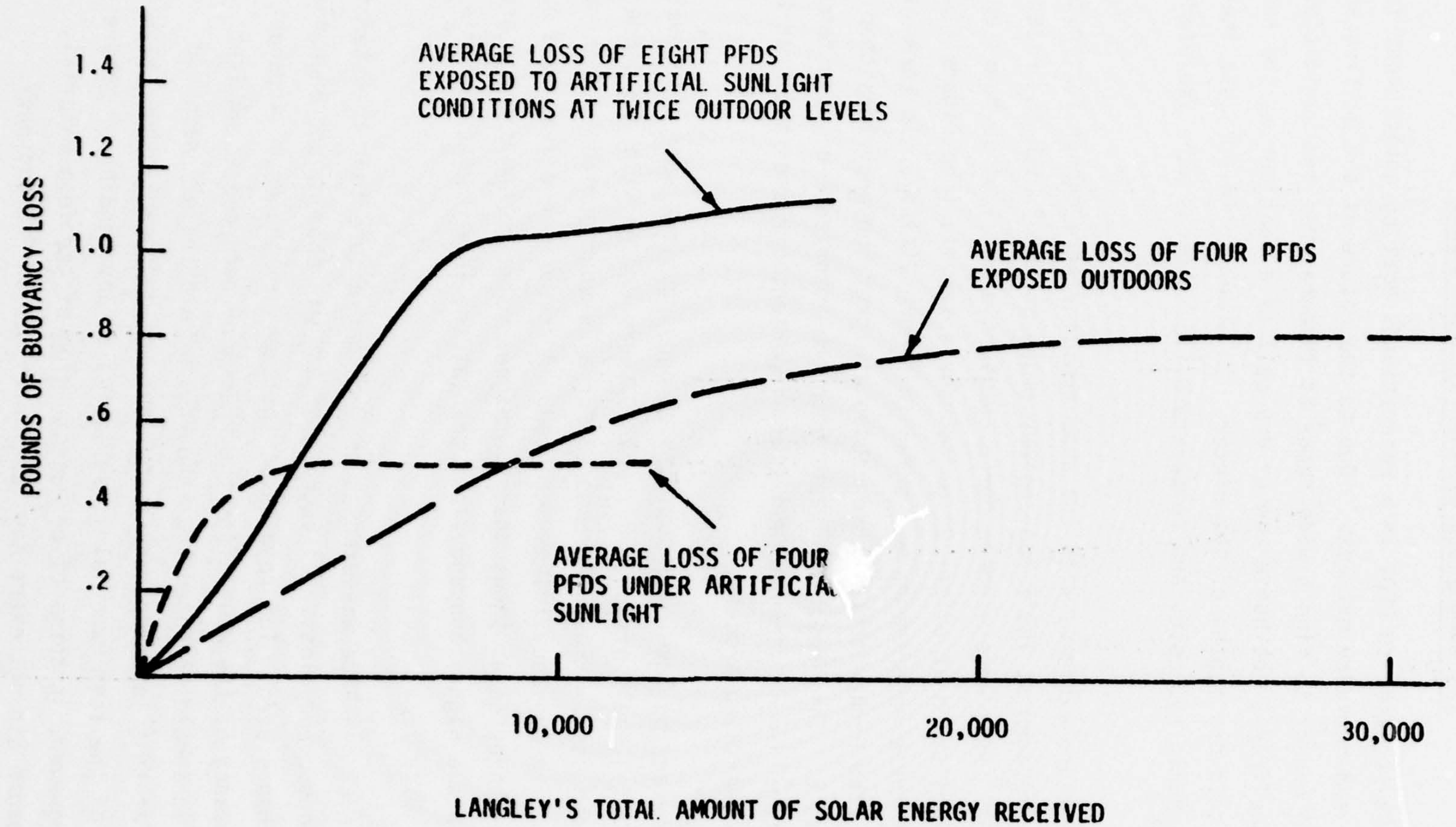


FIGURE V(A)-15. COMPARISON OF BUOYANCY LOSS FOR PVC FOAM PFDS UNDER THREE SUNLIGHT CONDITIONS

3.3 Temperature/Humidity Experiments

Another possible stressor to PFDs in a recreational boating environment is that of temperature and humidity extremes. Due to the nature of the boating activities, one would expect to find a wide range of temperatures and humidities. This could range from a hot humid bow or dry well of a boat during the summer months to the cold dry months of the winter. In order to investigate these effects, heat, humidity, cold, and temperature fluctuations were isolated and examined.

Two high temperature extremes with the same humidity were chosen for initial aging. PFDs were aged at 180°F and another group at 140°F with the relative humidity at 70%. PFDs were exposed for a cumulative total of 96 hours and buoyancy readings taken at either 24 or 48 hour intervals (see Figure V(A)-16). The results of these experiments are shown in Figure V(A)-17. In terms of buoyancy loss, the higher temperature causes a higher buoyancy loss than at the lower temperature. This result suggests both the importance of high temperatures as a natural aging stressor and as an important stressor that can be used to accelerate the aging process.

The effects of varying levels of humidity on buoyancy loss were also evaluated. Relative humidity levels of 30%, 50%, and 70% were chosen with the temperature at 180°F in each case. PFDs were exposed for a 24-hour period in each case and the respective buoyancy losses measured. A comparison of the mean buoyancy loss among the three cases shows that the higher relative humidities (greater than 50%) showed a higher buoyancy loss than at the lower relative humidity ($t = 3.6$, $p < 0.2$).

Next, a sample of new PFDs was exposed to a cold exposure test to determine the effects on buoyancy loss. An extreme of 0°F was chosen, and an exposure period of 72 hours used. The results of the exposure showed no apparent effect on buoyancy of the PFDs after the PFDs were returned to ambient conditions. It should be noted that the PFDs were extremely hard and brittle when at this low temperature and thus would probably show cracking and breaking of the foam material if subjected to any bending or compression stressors. However, in terms of permanent aging of the foam material, the cold exposure did not exert any lasting effect on PFD buoyancy.

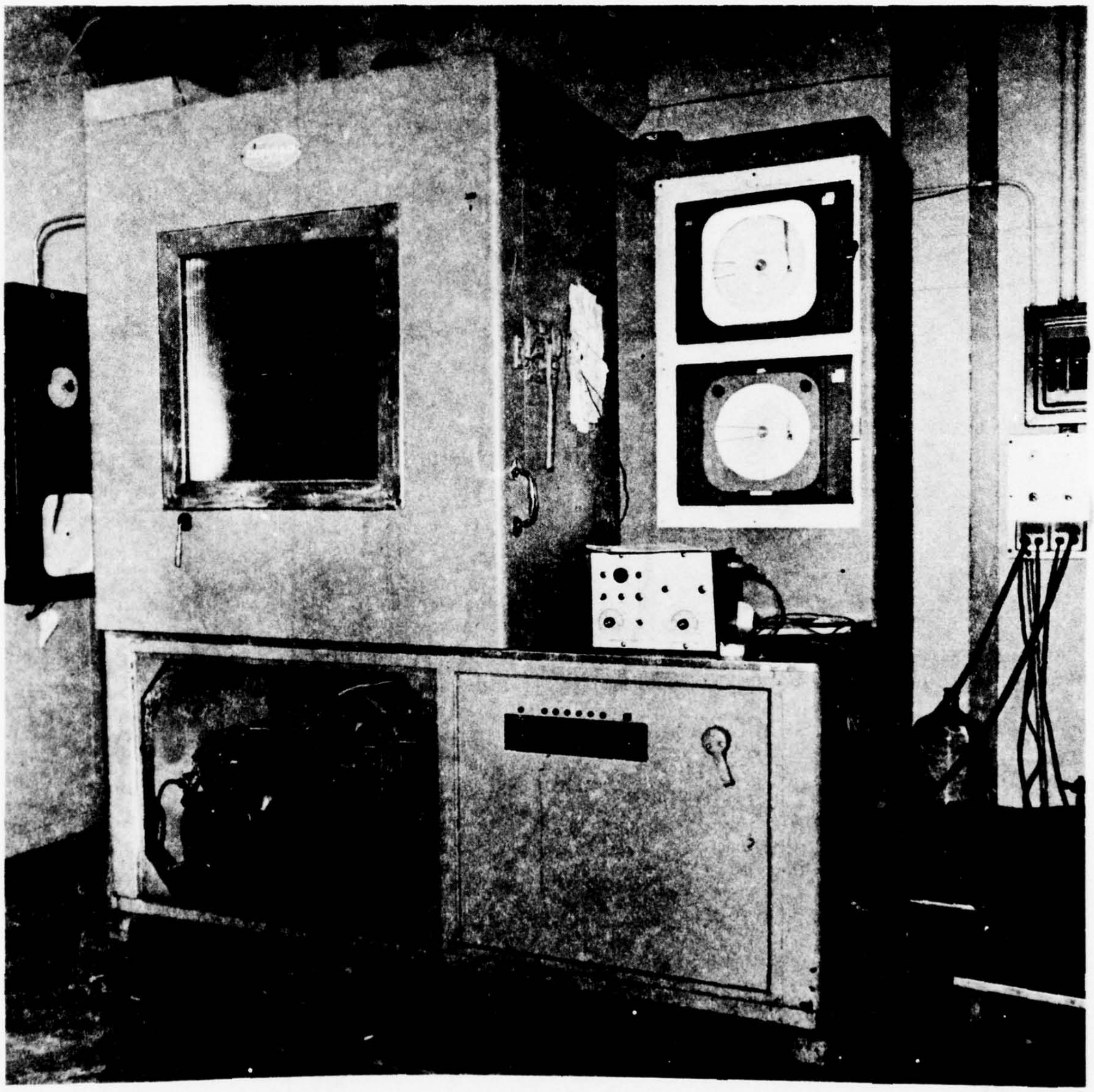


FIGURE V(A)-16. TEMPERATURE AND HUMIDITY CHAMBER USED FOR PFD EXPOSURE TESTING

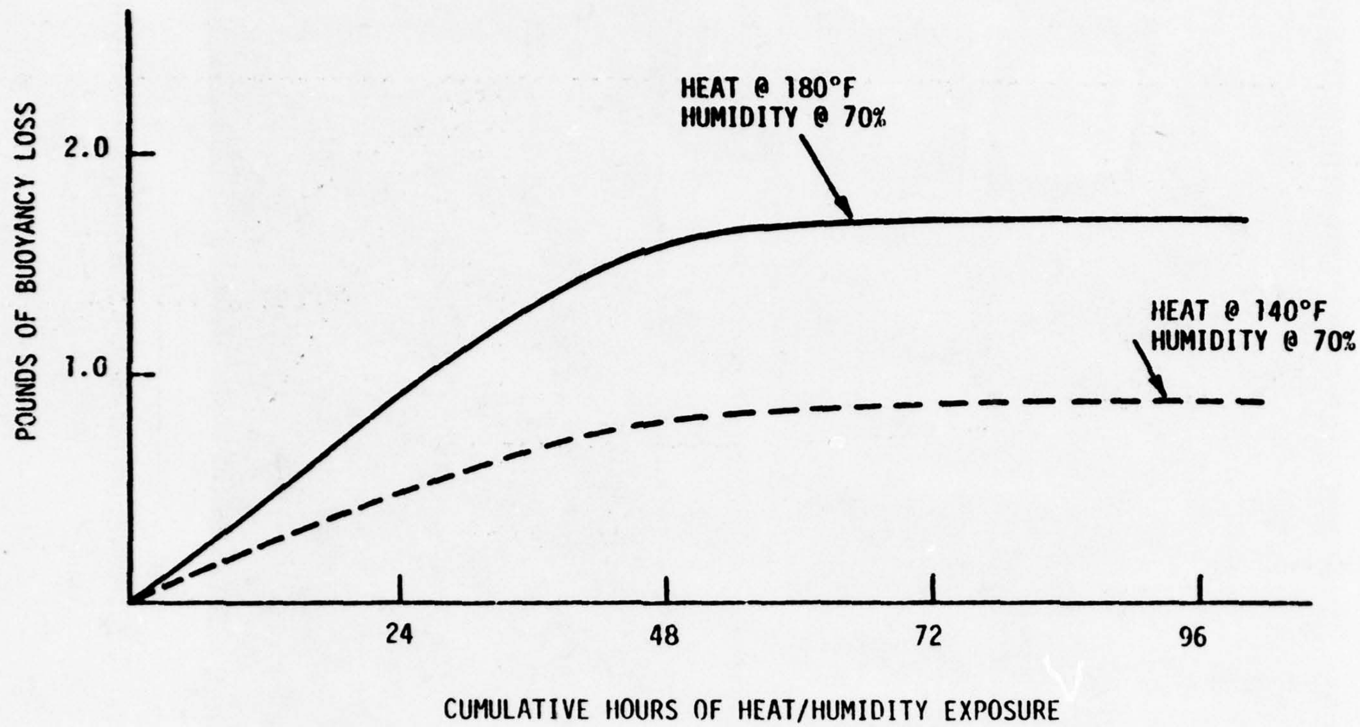


FIGURE V(A)-17. RESULTS OF HEAT/HUMIDITY EXPOSURES

Another possible PFD stressor to be examined is that of exposure to extremes of both heat and cold and subsequent breakdown of the foam material or PFD structures by the continuous cycling between these extremes. An experimental exposure of this type was designed whereby PFDs were exposed to an extreme of 160°F for six hours, a transition period for six hours, and a cold exposure of 10°F for six hours. PFDs were left in this cycling mode for a period of 72 hours and the buoyancies of the PFDs measured afterwards. The results showed that the cycling of PFDs through these extremes caused an average buoyancy loss of only 0.1 pounds for this exposure period. The cycling of PFDs through temperature extremes does not appear to be a significant stressor.

3.4 Salt Spray Experiments

In the design of an accelerated aging sequence, consideration must be given not only to the buoyancy medium but to other parts of the PFD as well. The part that is of interest here is the fastening mechanism. The fastening mechanism usually consists of either some type of snap closure or zipper. The types of failures that can occur could be due to one or both of the following:

1. Corrosion of some part of the fastening mechanism can occur thus rendering it either hard to operate or inoperable in an emergency situation. Results from the PFD effectiveness study have shown the difficulty with which most PFDs are donned in the water. The added component of having a difficult fastener to use could prove to be costly in an emergency situation.

2. A general breakdown of the fastener mechanism could result due to inherent quality control problems, random failures due to physical damage, and failures due to wearout of the fastening device.

As reported earlier, the results from the analysis of the fastener mechanisms employed by the variety of PFDs collected suggested that failure of the fastener does not seem to be a problem. Of the PFDs collected, wearout of the fastening mechanism does not seem to be a problem. In addition, the results of the analysis of zippers for operability force showed that their usage environment

does not seem to lead to corrosion problems. The results from the analysis of the zippers exposed to the individual stressors of sunlight, heat, humidity, and cold agreed with the results from collected used PFDs.

However, it was recognized that a corrosive element such as salt spray could lead to hardware failures. Therefore, testing was performed in order to determine the extent to which salt spray could be a factor (see Figure V(A)-18). In this experimental design, PFDs employing two different size zippers were exposed to over 100 hours of the standard salt spray exposure test (MIL STD 810C) using a 5% salt solution and a temperature at 95°F. PFDs were examined and tested for both difficulty in use of zippers and loss of buoyancy after this exposure period. The results showed that the salt spray had a definite corrosive effect on the zippers with the larger size zipper performing much better than the smaller size. The smaller size zipper was inoperative in both cases after the 100 hours of salt spray. Measurements were also taken of the buoyancy loss for the 100 hours of salt spray exposure. An average buoyancy loss of almost 0.3 pounds was observed. This buoyancy loss is probably the result of exposure to the high temperature rather than as a result of exposure to the salt spray.

These results suggest the following:

1. A salt water boating environment could lead to a higher rate of failure among zippers.
2. PFDs with proper size zippers could be acceptable in salt water environments.
3. A necessary component of any accelerated aging sequence would be the inclusion of salt spray for testing of hardware components.
4. The collection of PFDs that were used in a salt water environment is necessary in order to determine the extent to which salt water corrosion is a problem.

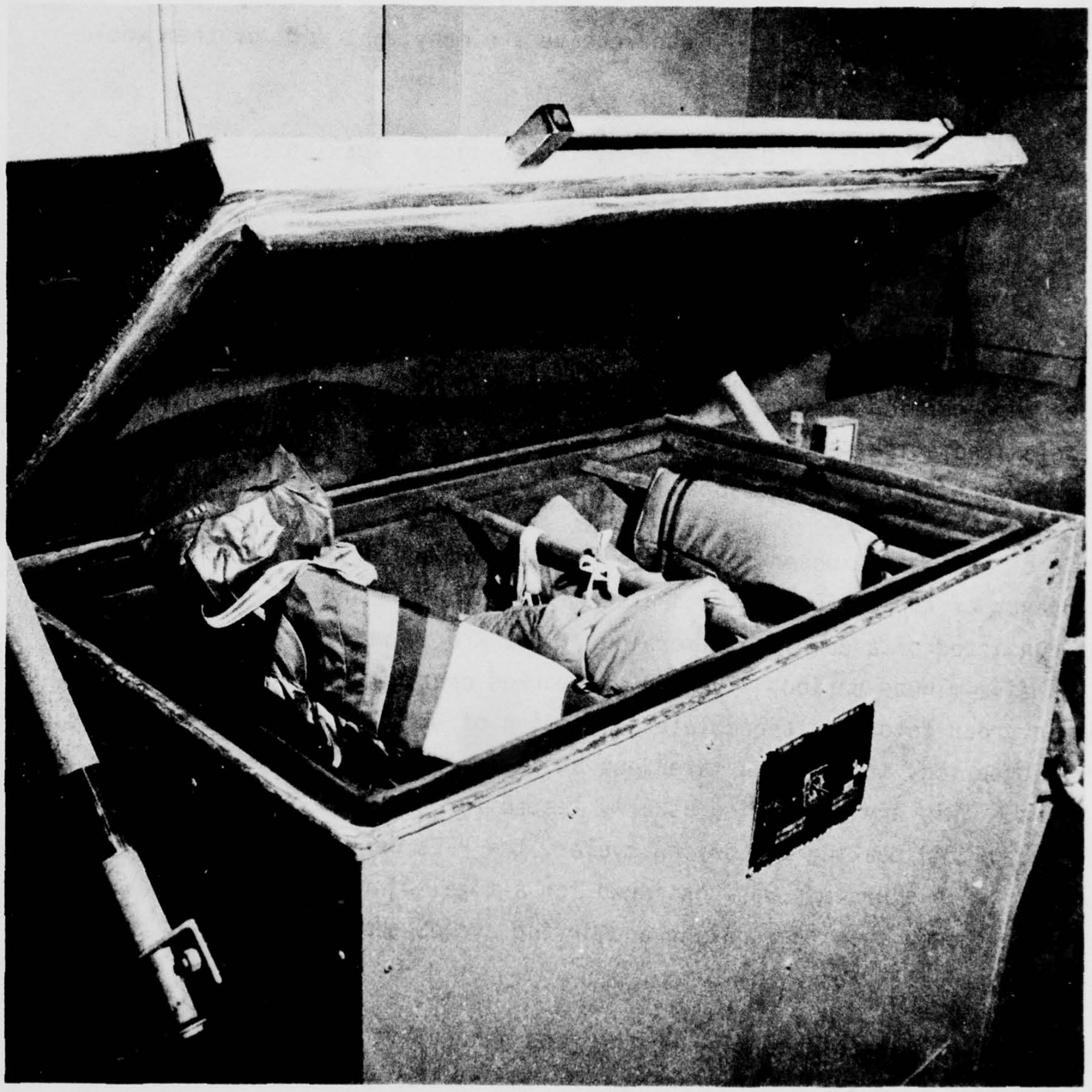


FIGURE V(A)-18. SALT SPRAY CHAMBER USED FOR PFD EXPOSURE TESTING

3.5 Usage/Abuse Experiments

The identification and design of test procedures to simulate the various types of physical abuse that a PFD would normally receive is a more difficult task. The types of use or misuse that a PFD can receive are many, but most of them would fall under one of the following:

1. the wear that a PFD receives by the continual soaking and drying involved in the normal use of the PFD
2. the wear that a PFD receives from the actual donning of the PFD, compression and relaxation of the foam material, and the abrasive type wear that both the covering material and foam is exposed to.

In order to determine whether stressors such as these need to be included in the accelerated aging sequence, an experiment was designed to determine the effects of each of these stressors.

A sample of PFDs was exposed to a series of soaking and drying cycles and the buoyancy of these PFDs measured afterwards. The soaking and drying cycles consisted of a complete immersion of the PFD in water for approximately a five-minute period. The PFD was worked continuously for this period in order to obtain a complete saturation of the foam material. After this period, the PFD was taken out and allowed to dry at ambient conditions. This dry out period usually lasted for three to four hours. At the end of ten soaking and drying cycles, the PFDs were measured for loss of buoyancy. This process was continued for a total of thirty cycles. The results showed that the soaking and drying cycles had no effect on the buoyancy of the PFDs.

The next problem was to determine whether the general factor of usage, in particular that associated with the compression of the foam material, would have a deteriorating effect on the foam's cell structure. In order to simulate the possible deteriorating effect of this general usage, a test was designed to effect a compression/relaxation of the foam material and an abrasive type wear of the foam, covering material, and associated parts. The most common type of compressive weight that a PFD is exposed to is that of being sat or leaned upon. A preliminary calculation showed that this weight

was of the magnitude of approximately 1/2 of the total body weight. Therefore, with the weight of an average man at 150 pounds, the weight to be used in this test was 75 pounds. It was decided that bags of buckshot would provide the best means to simulate the required weight, and therefore, three 25-pound bags of buckshot were arranged in a canvas covering bag. The weight covered approximately the entire area of a folded PFD which was 1 foot by 2 feet. This weight was strapped on top of the test PFD, and the entire arrangement set into a specially built box on a vibration table. Various combinations of frequency and amplitude were experimented with on the vibration table. The purpose of experimenting with various frequencies and amplitudes was to establish that combination that would provide an "out of sync" effect between the PFD/weight setup and the vibration table. This bouncing effect would thus provide a simulation of both the abrasion and compression of the PFD. Using this approach, an optimal combination of 11 hertz and .4 inch displacement was arrived at.

Using this setup, an experiment was designed to test the effects of the abrasion/compression stressor on PFDs. It was hypothesized that two modes of breakdown could contribute to PFD degradation: (1) the general usage of the PFD could lead to the abrasive wear of both the foam and covering material, (2) the compressive wear of the PFD could contribute to breakdown of the closed-cell foam and other PFD components. PFDs from three groups were exposed to the abrasion/compression stressor on PFDs. The three groups consisted of a sample of brand new foam PFDs, a sample that had been exposed to some natural aging and a sample that had been exposed to some accelerated aging. Each group was exposed to the abrasion/compression test for a two-hour period and buoyancy reading taken before and after each exposure. The results showed that PFDs that had received some sort of previous aging, either accelerated or natural, had some buoyancy loss after two hours of abrasion/compression. The PFDs under natural aging lost 0.4 pounds buoyancy, and those under accelerated aging lost about 0.3 pounds buoyancy. The new PFDs showed no buoyancy loss after two hours of abrasion/compression testing (see Figures V(A)-19 and V(A)-20). The following conclusions can be drawn from these results.

1. The abrasion/compression type of wear that PFDs receive during usage is a contributing factor in PFD degradation.

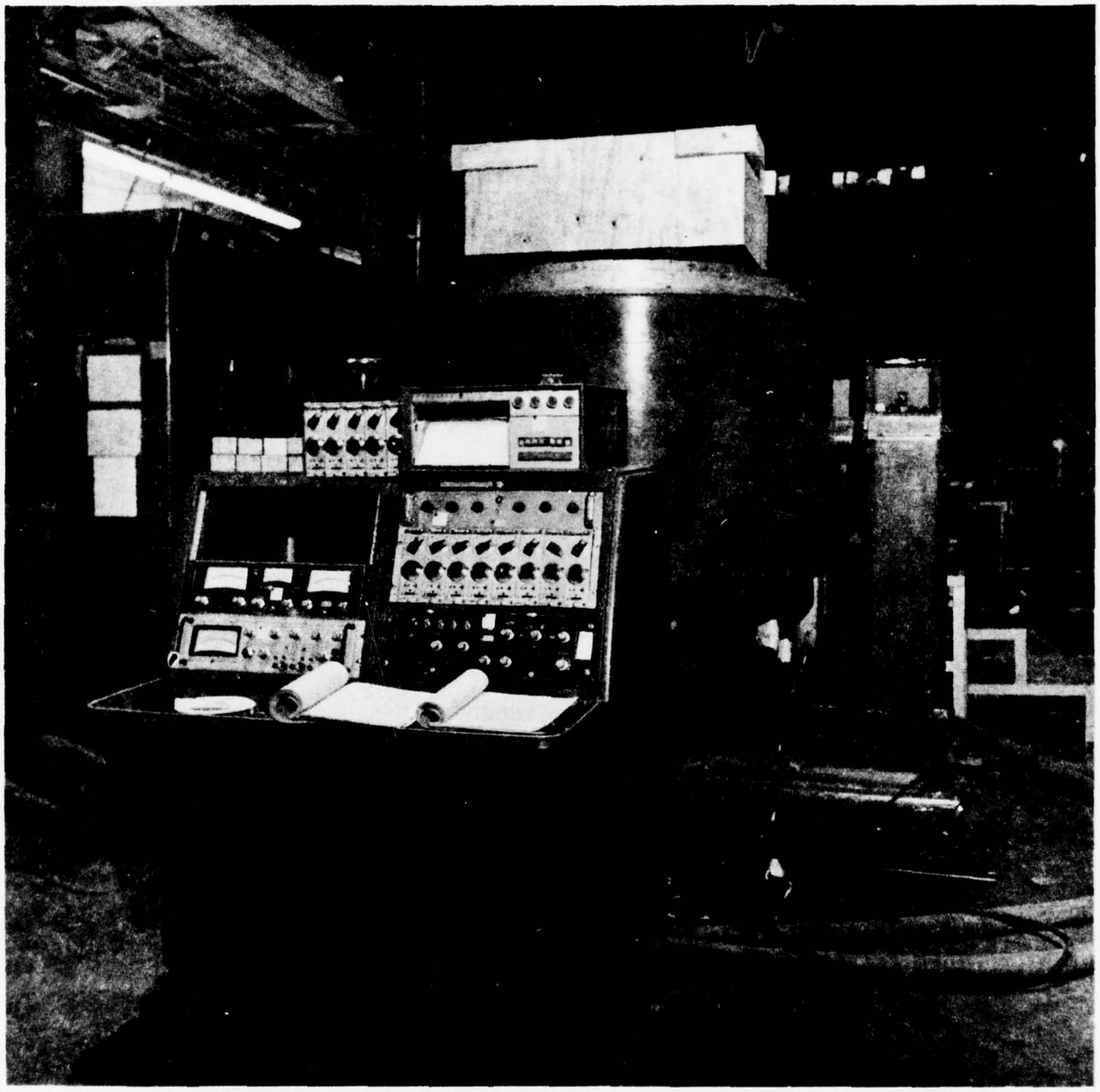


FIGURE V(A)-19. TEST SETUP FOR PFD ABRASION/COMPRESSION TESTING

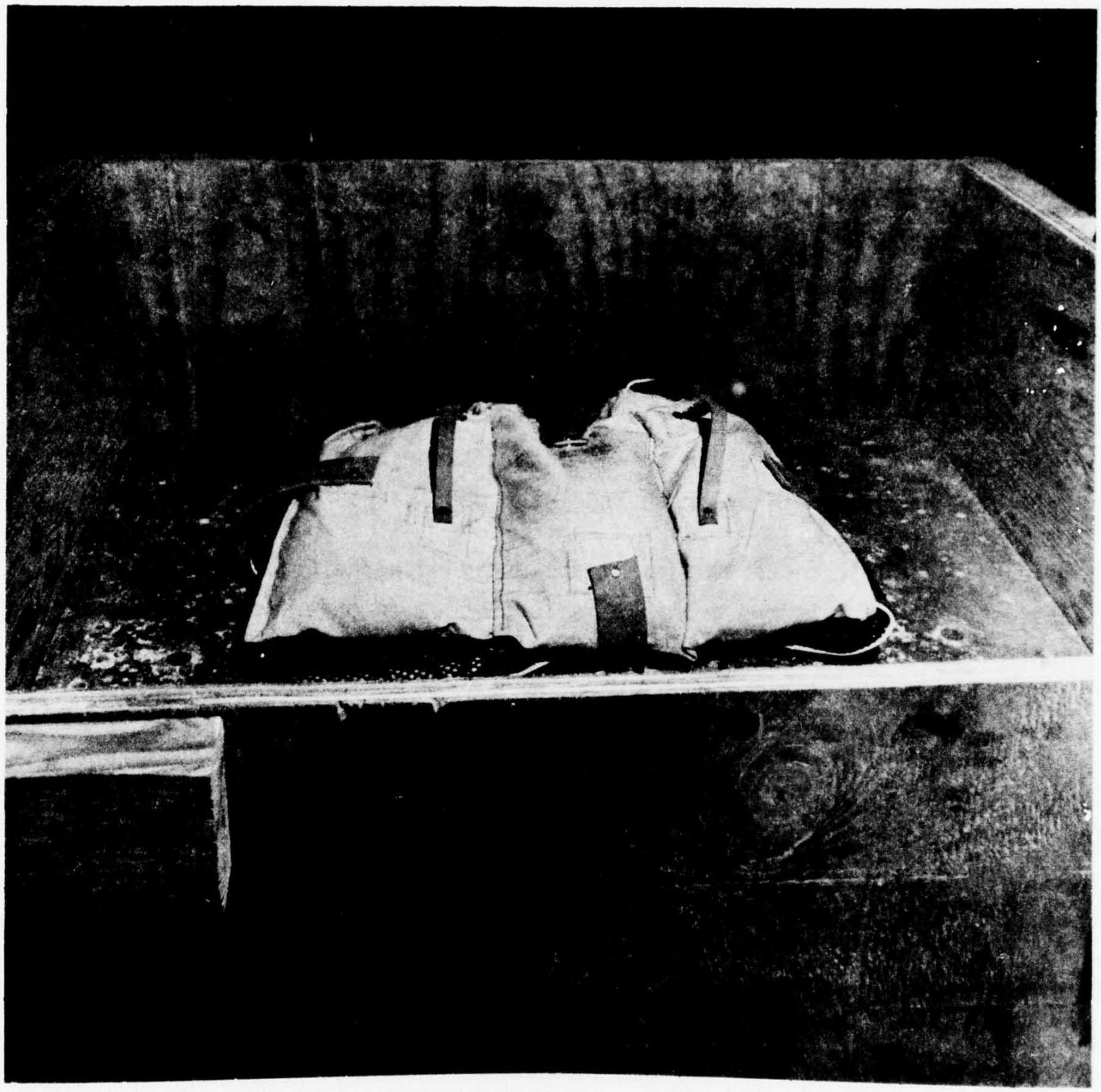


FIGURE V(A)-20. PFD AND WEIGHT ARRANGEMENT FOR ABRASION/COMPRESSION TEST

2. Since loss of buoyancy occurs only after some other stressor has aged the PFD, the loss of buoyancy is probably due to either the abrasion, cracking, and/or compression of foam material made brittle by exposure to other stressors.

3.6 Analysis of Results

The results from this section have provided the guidelines for modeling an accelerated aging sequence. Several criteria have emerged as important in the selection of the appropriate aging tests.

1. The selection of a test for use in the accelerated aging sequence must consider whether the information returned is worth the cost required to run the test.

2. Consideration must be given to any interaction and/or synergistic effects that occur in order to model the degradation process properly.

3. The selection of tests must examine closely both the environmental stressor as well as the probable failure modes in order to assure that both areas have received consideration.

3.7 Selection of Accelerated Aging Tests

Based on the previous results, four stressors have been chosen for use in the accelerated aging sequence. The following tests were chosen based both on the desire to simulate natural conditions as much as possible and to develop a cost effective test procedure.

SUNLIGHT - The results from exposure to both natural and artificial sunlight conditions revealed that a degrading of the PFDs did occur. An analysis showed that both the heat generated from the infrared sunlight range and the actinic degradation were responsible for PFD degradation. Due to this and the fact that PFDs are by nature of their use exposed to intense sunlight conditions, it was decided that some type of sunlight exposure in the accelerated aging sequence was important.

HEAT/HUMIDITY - The results from the exposure of PFDs to a variety of heat/humidity conditions showed that this combination was degrading and in particular, a condition of high humidity and heat was worse than that of low humidity and heat. Due to this result and the fact that boating environments usually high humidity environments, a stressor of high heat and humidity was included in the accelerated aging sequence.

SALT SPRAY - The inclusion of salt spray in the accelerated aging sequence was felt to be important from a hardware standpoint. The results from the exposure of various size zippers to salt spray showed that corrosion could be a significant factor affecting PFD operation. Therefore, a salt spray exposure was included in order to assure PFD operability in a corrosive environment.

ABRASION/COMPRESSION - The results from this testing has indicated the importance of including a test to simulate the wear a PFD might receive. Of particular interest was the synergistic effect of combining the abrasion/compression test with another stressor. Results such as these are important from the overall accelerated aging standpoint.

3.8 Discussion

The aging sequence developed has been an attempt to model as many environmental/usage stressors as possible for a cost, time, and practicality standpoint. The results from the use of this aging procedure have shown that it is capable of detecting latent failure modes (i.e., loss of buoyancy or mechanical failures) in both inherently buoyant and inflatable PFDs (Section V-B). Therefore, the aging procedure is valid in its present form for most types of PFDs. However, since only one type of PFD was collected and used as an environmental/usage model, there is a possibility that an environmental stressor exists which was insignificant in terms of PVC foam PFDs and the inflatables tested, but which is significant in some other type of PFD. If this environmental stress is found to exist, then it would have to be included in order to form a more generalized model. A more generalized environmental model would not delete any of the current tests, but would instead include any other tests found to be significant. However, since the accelerated test sequence accurately models the environment, it is unlikely that any other environmental factor exists which is significant.

The results from this research have shown that interactions among the stressors used in the aging procedure are important considerations. The major strength of performance oriented tests is that the performance of the entire PFD is evaluated, so that interactions among stressors are considered. Since the accelerated aging procedure is meant to model the environment, salt spray, a significant stressor, has to be included. Even though the only parts of the PFDs tested which were found to be susceptible to the deleterious effects of salt spray were the zippers, this does not guarantee that a new style of PFD or style not tested may contain components or be constructed in such a way as to be severly degraded by salt spray. Salt spray needs to be included because it is a forseeable hazard for the entire PFD. Testing only portions of a PFD to any hazards assumes a control over the manufacturing and materials in order to preclude deleterious effects.[1] This assumption also carries a liability in the event of a failure of a PFD to operate properly in a salt spray environment. For example, even though a zipper may pass a salt spray test, the combined aging sequence could cause it to fail. Another example could be that two manufacturers use the same type of zipper, however, the results after the aging procedure might show that one manufacuturer used inferior stitching to attach the zipper to the PFD; therefore, his PFD would not pass. In order for performance tests to effectively detect failure modes such as these, the aging must be performed on the entire PFD and not parts of it.

The aging procedure developed for use with recreational boating PFDs has made use of relevant Mil-Stds and ASTM standards where these were found appropriate. These standards have been used in the manner and purpose intended; that is, as a general guide for developing the more specific aging procedures for recreational boating PFDs. ASTM procedures are construction standards, and the use of construction standards by themselves does not take into account the interactions and synergistic effects. ASTM recognizes the limitations of their own test procedure and says[2],

---

[1] Testing components of a PFD separately is acceptable in cases where one has sufficient control over and knowledge of the materials and construction of the PFD and the quality control to which it is subject.

[2] Taken from Wyle Laboratories Technical Brief 77-03, "Review of Factors Relevant to Establishing a Methodology for Determining the Reliability of PFDs," by Michael J. Pfauth, February 1977.

"... While useful for other purposes, results obtained by the use of this recommended practice should not be represented as equivalent to those of any natural weathering test or tests until the degree of such correlation, if any, has been established for each material."

The MIL-Stds are not directly applicable in most instances, since they do not represent the recreational boating environment. The intent of these standards and basic procedures has been used with parameters modified to represent conditions found in recreational boating.

4.0 DEVELOPING THE ACCELERATED AGING SEQUENCE

4.1 Method

Ideally, one of the main goals in developing a valid accelerated aging sequence is to attempt to "model the environment" to which the test item is to be exposed under normal conditions. Obviously, as the degree to which the model simulates the normal aging process increases, the cost to produce such an accelerated environment increases. Therefore, the development of an accelerated aging sequence is an attempt to arrive at a cost tradeoff between modeling the natural environment and developing a cost effective accelerated aging sequence. In order to arrive at this optimum tradeoff point and still provide a valid accelerated aging sequence, this method should meet the following criteria.

1. The limit to which the intensity of individual stressors can be raised and not introduce new failure modes should be established.

2. The distribution of the failure rates under the accelerated test sequence should come from the same general family of failure distributions as those under normal stress conditions. One author (Reference 3), in discussing the response of a test article to accelerated testing, states this requirement as follows, "The essential requirement is that the response to accelerated testing be independent of the dose rate; i.e., that it depend only on the total dose."

3. There should exist both a statistical model and empirical evidence to support that model showing the time transformation between accelerated aging and normal aging.

4. The accelerated aging sequence should take note of any interactions or synergistic effects that occur and include their effects on the reduction of test time.

4.2 Results

Basically, the approach taken in developing the accelerated aging sequence is that of first determining the limit to which the stressor intensity may be validly set and then adjusting the length of exposure to the accelerated test sequence to obtain the desired level of degradation. The major advantage to this method is that the minimal amount of time needed for accelerated aging will be used.

The limits to be used for the intensity of each accelerated stressor were obtained by a consideration of either the limitations of the test chamber, test item limitations, or as the result of previously set specifications. The limit for the intensity of sunlight that could be used is due to the requirement of maintaining a temperature of between 140°-145°F within the PFD and providing a distribution of solar energy such that the proportion of ultraviolet energy is at least representative of normal conditions. Due to these constraints, the maximum intensity of the solar irradiation was 1.17 Langleys/minute. This is slightly below the average level of solar energy of 1.36 Langleys/minute found under normal outdoor sunshine conditions. The level of temperature and humidity to be used for the heat/humidity stressor was set at 160°F and 95% relative humidity. These limits were set in order to maintain the temperature below design limit for most foam materials and at a high humidity to simulate humidities most often encountered under boating conditions. The temperature and salt spray concentration in the salt spray test were set at the same levels as those recommended in MIL-STD 810C for environmental testing. The intensity level used for the abrasion/compression test was arrived at by the method discussed earlier.

The next step in developing the accelerated aging sequence is to combine the stressors and to note whether any interaction or synergistic effects occur. The test sequence for combining the stressors was obtained from the U. S. Army Test and Evaluation Command, Material Test Procedure 6-2-532, Appendix B. The recommended test sequence is heat/humidity, sunlight, salt spray, and abrasion/compression.

Based on the results from the individual stressor experiments, an estimate was made of the probable degradation after a new PFD was exposed to each of the following stressors:

1. HEAT/HUMIDITY for 24 hours at 160°F with 95% relative humidity
2. SUNLIGHT EXPOSURE for 144 hours at 1.17 Langleys/minute with PFD temperature at 140-145°F (total sunlight energy measuring 10100 Langleys)
3. SALT SPRAY for 48 hours at 95°F with 5% salt spray solution
4. ABRASION/COMPRESSION for 1 hour at 11 Hz with 0.4 inch displacement, using 75 LBS overall or approximately 0.35 PSI.

The estimated loss of buoyancy for these PFDs based on the results of the individual stressor experiments is 1.5 lbs. The actual loss after exposure to this accelerated aging sequence was 2.0 lbs. This result again suggests that some interaction or synergistic effect is occurring among the stressors, thus leading to the loss of this additional 0.5 lb of buoyancy.

These same PFDs were exposed to two more accelerated aging cycles and buoyancy measurements taken after each cycle (Figure V(A)-21). If a comparison is made between this buoyancy loss curve and buoyancy loss curves for the individual stressor experiments, a major difference is noted. The buoyancy loss for individual stressors shows a definite leveling off after a period of rapid buoyancy loss. The buoyancy loss for PFDs after several accelerated aging cycles also shows an initial rapid buoyancy loss, however, does not level off as in the individual stressor results. The buoyancy loss in these latter two cycles is not as great as the initial loss; however, these PFDs still are losing buoyancy in the later cycles. This result is quite significant in that it again shows that some interaction and synergism among stressors is occurring. Therefore, any accelerated aging sequence developed must include all these stressors. The use of only one or two stressors to age PFDs will probably not give representative results in terms of aging and comparisons among the various PFDs.

Next, a new set of PFDs were aged by the same accelerated test sequence; however, the length of the cycle was shortened as follows:

1. HEAT/HUMIDITY for 12 hours
2. SUNLIGHT EXPOSURE for 72 hours
3. SALT SPRAY for 24 hours
4. ABRASION/COMPRESSION for 0.5 hour

The results from this aging showed the buoyancy loss assuming similar characteristics as that of the previously aged PFDs. These results are also shown in Figure V(A)-21. An analysis of these results is shown in Figure V(A)-25. All the accelerated aging results are plotted as failure data. This shows that the buoyancy loss of the PFDs under artificial aging responds in a linear fashion, and that dose rate does not affect the aging process. A comparison was also made between the buoyancy loss for long and short duration periods but for similar exposure periods. No significant difference was found ($t = .69$, $p > .2$), thus proving that dose rate does not affect buoyancy loss.

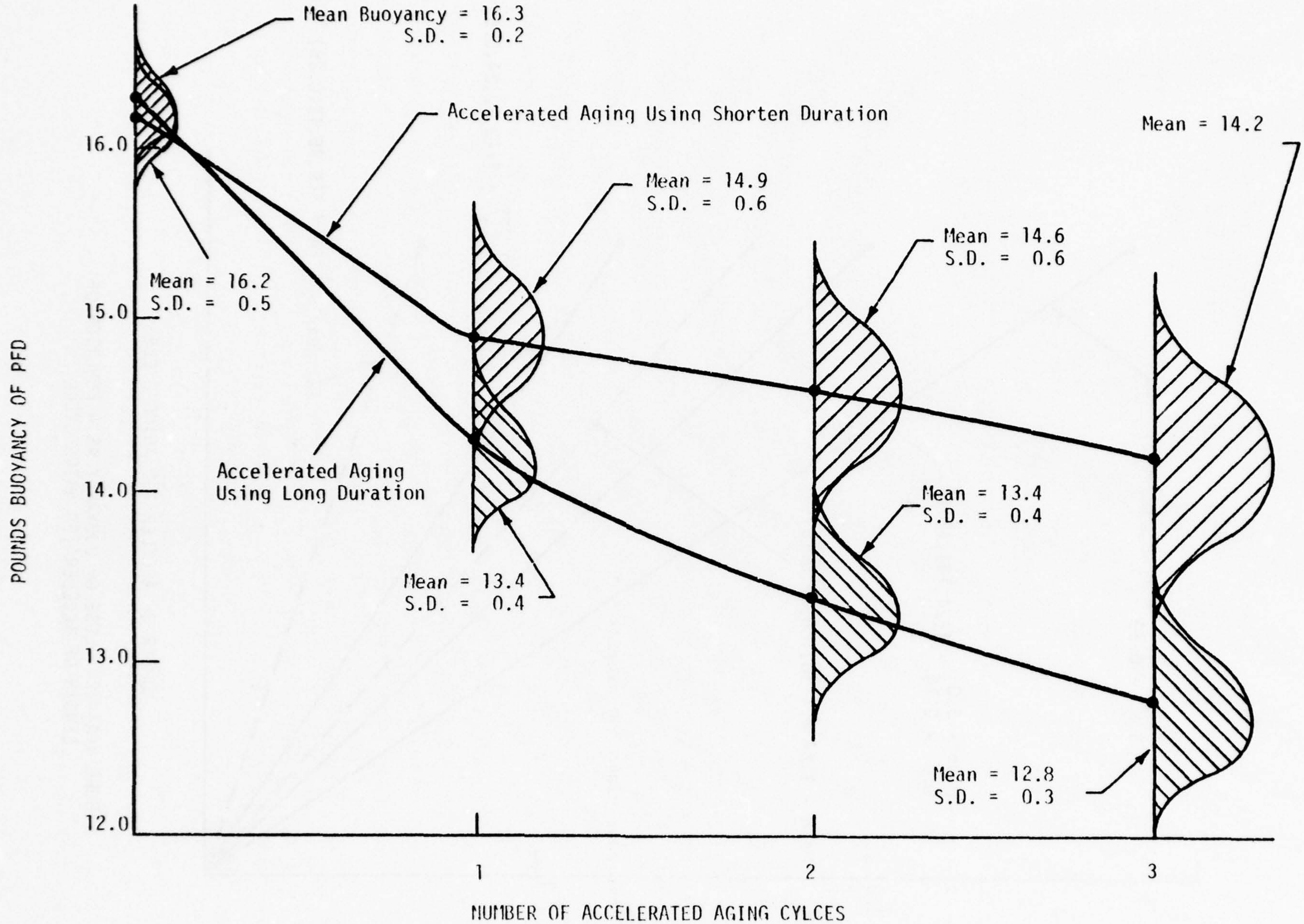


FIGURE V(A)-21. RESULTS OF ACCELERATED AGING OF PVC FOAM PFDS

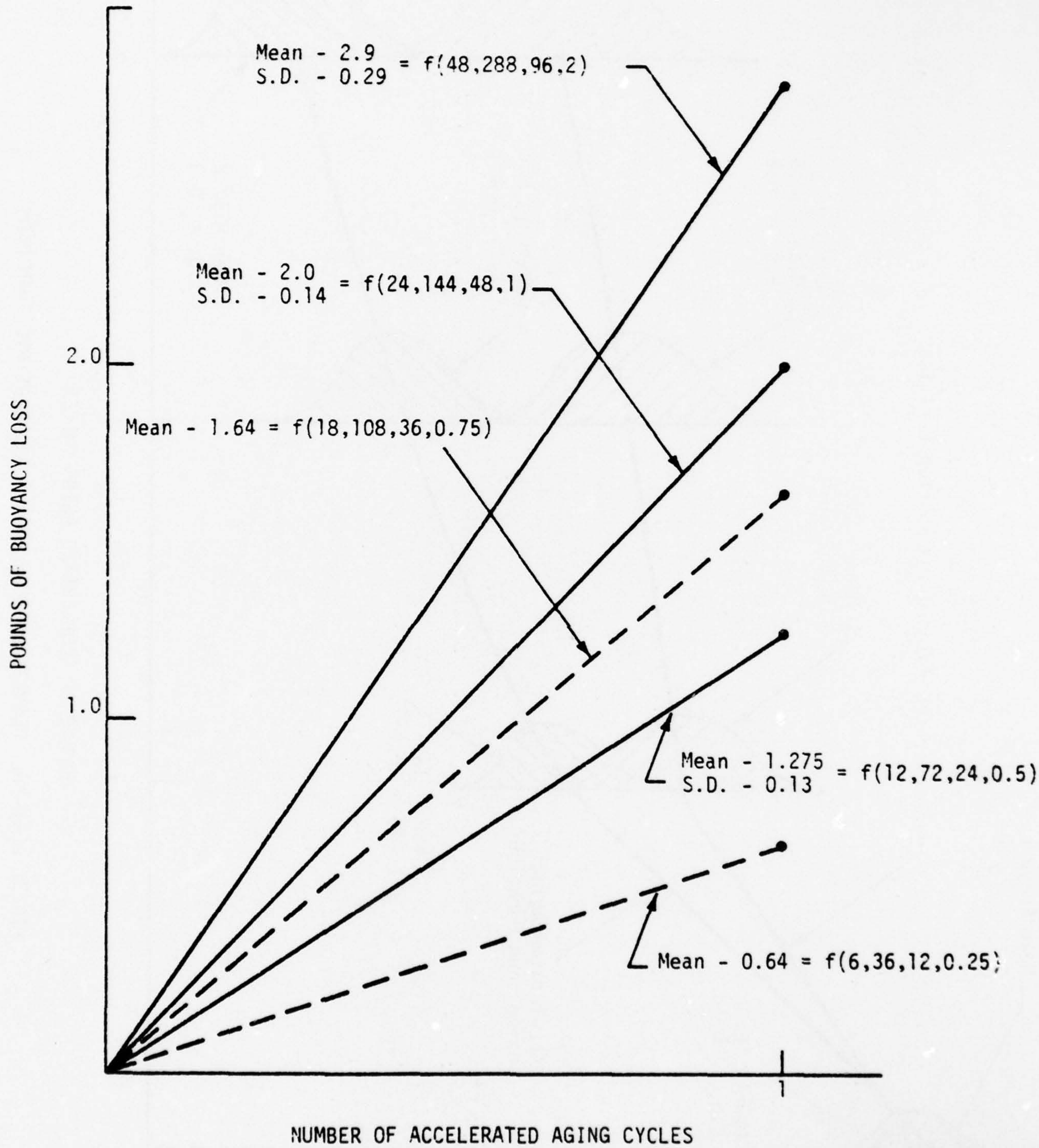


FIGURE V(A)-22. LOSS OF BUOYANCY AS A FUNCTION OF LENGTH OF ACCELERATED AGING CYCLE

Figure V(A)-22 shows these results plotted as buoyancy loss after one accelerated aging cycle. This graph shows that the desired amount of accelerated aging may be obtained by varying the parameter of length of exposure. The solid lines represent actual test results while the dotted lines are the result of interpolating and extrapolating the data.

4.3 Validation

In order to determine the validity of the accelerated aging methodology that has been developed, both a quantitative and qualitative comparison betwen normal and accelerated aging results can be made.

A qualitative evaluation of the results of accelerated and normal aging was made to determine the types of failure modes encountered. An examination of the used PFDs collected showed that buoyancy loss seemed to be due to loss of volume, deterioration and wearing away of outer layer of foam material, and/or the cracking and breakdown of the closed cell structures. The younger PFD's buoyancy loss seemed to be due strictly to a loss of volume but the older PFDs showed more evidence of the closed cell structure breaking down such as in the cracking seen. The PFDs that underwent accelerated aging showed a similar loss of volume and deterioration of the outer foam layer; however, very little cracking of the foam appeared. Cracking of the foam would probably occur if more accelerated aging was performed (see Figure V(A)-23).

The results of accelerated and natural aging were also compared on the basis of type of failure distribution that was observed. Both sets of data were converted to failure rate by choosing a failure criteria of 14.7 lbs of buoyancy (see Effectiveness Section). The data was fit to several types of failure distributions and the best fit chosen. Both the naturally aged and accelerated aged populations were found to fit log normal distributions with a high level of confidence ($r^2 = 0.93$ and 0.96, respectively). These results are shown in Figures V(A)-24 and V(A)-25 with the 95% confidence interval plotted for both. Figure V(A)-24 shows that for Type III PVC foam PFDs, 50% will have less than 14.7 lbs of buoyancy after about 4.8 years of usage. Figure V(A)-25 shows the accelerated aging results plotted as a function of number of cycles where one cycle in this case is 24 hours heat/humidity, 144 hours of sunlight, 48 hours of salt spray and 1 hour of abrasion/compression. These results have shown that the failure distributions of both the accelerated and normally aged populations are similar, thus satisfying an important requirement of accelerated aging.

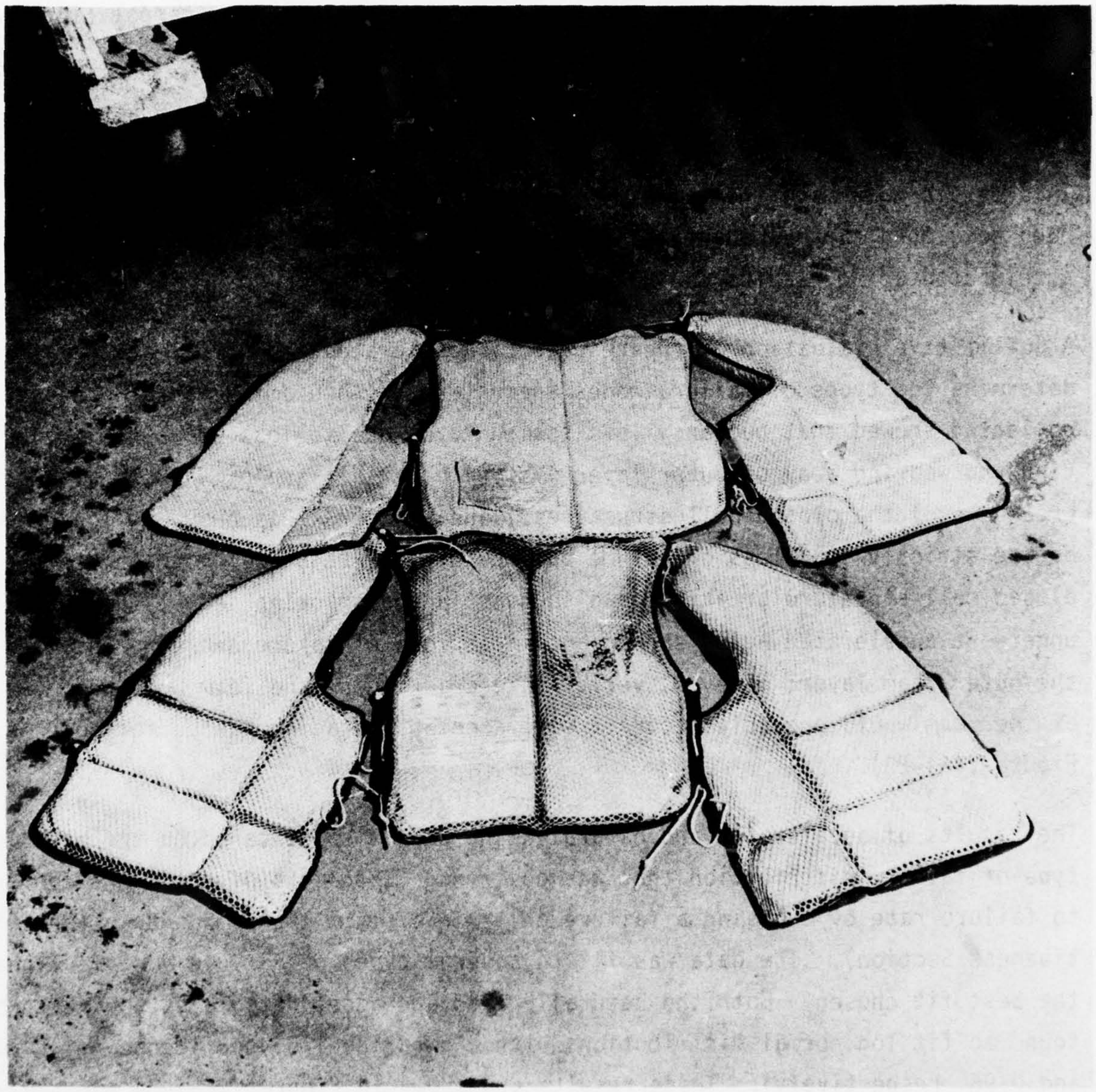


FIGURE V(A)-23. COMPARISON OF PFDS - TOP ONE IS AFTER SEVERAL YEARS NORMAL USAGE - BOTTOM ONE IS AFTER ACCELERATED AGING

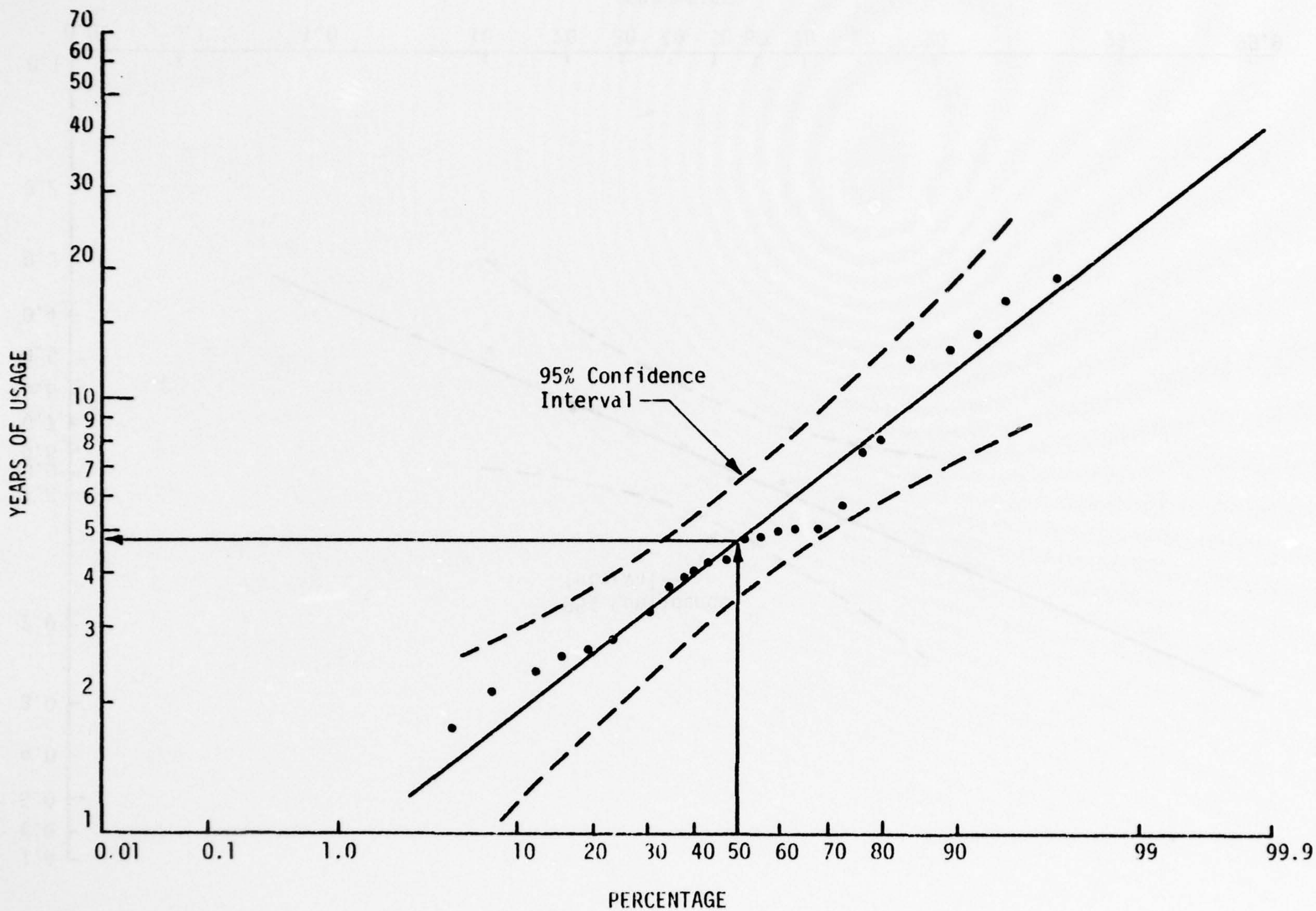


FIGURE V(A)-24. USED NORTH ALABAMA PFDS COLLECTED PLOTTED AS LOG NORMAL FAILURE DISTRIBUTION

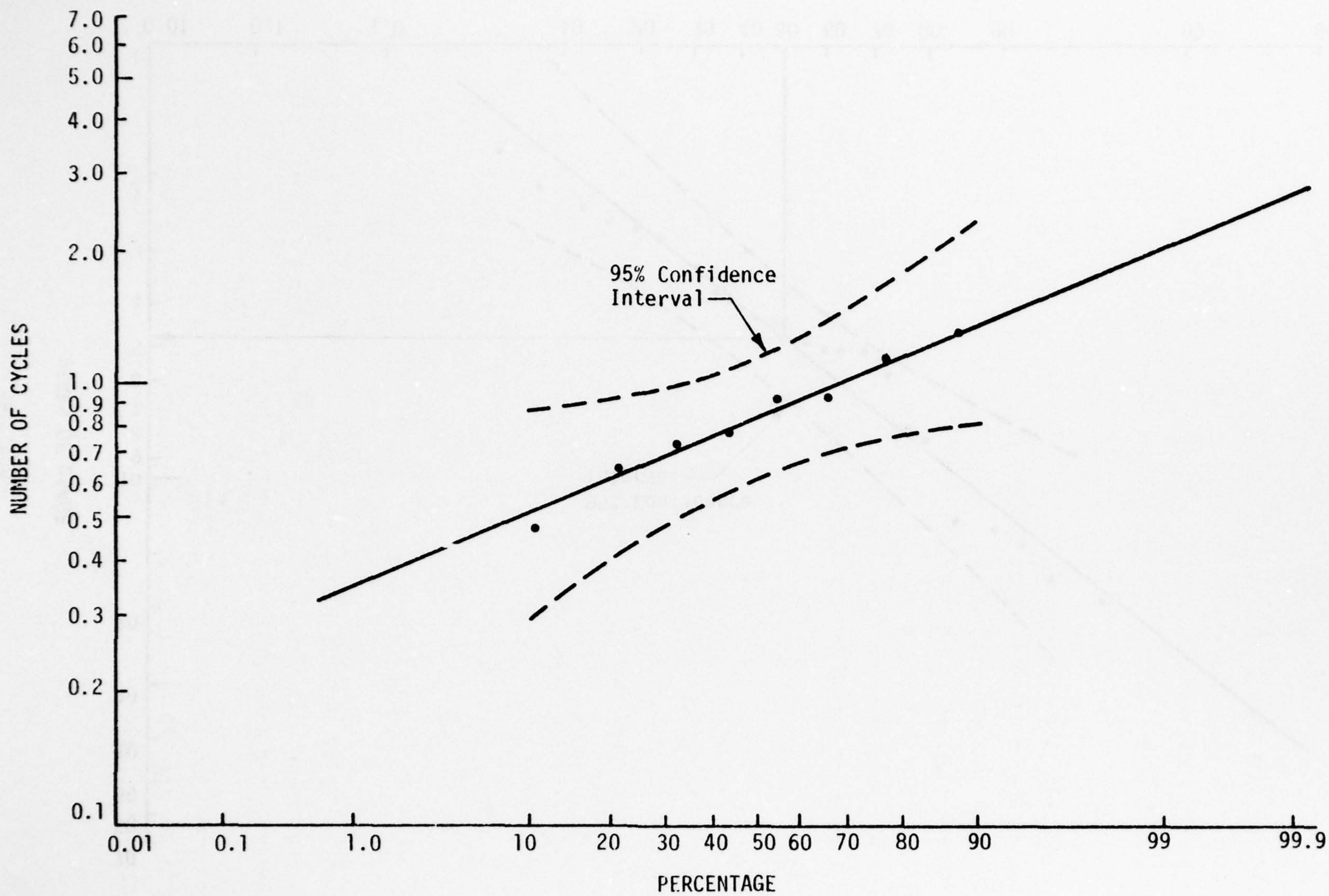


FIGURE V(A)-25. PLOT OF ACCELERATED AGING RESULTS AS LOG NORMAL FAILURE DISTRIBUTION

4.4 Time Transformation Model

Our next concern is that of developing a relationship between the normal and accelerated aging results. In particular, the purpose is to determine the length of exposure to the accelerated aging sequence needed in order to predict the buoyancy loss for a particular PFD after a period of usage in a recreational boating environment.

In Figure V(A)-26, the results from Figures V(A)-24 and V(A)-25 have been used to obtain a plot of the natural age of the PFD versus the accelerated aging time needed to reach that natural age. These results can be used to determine a time transformation model for converting accelerated aging results to natural aging time. Results from previous research (Reference 4) has shown that the form of the model for converting failure time under normal aging to failure times under accelerated aging, where both failure distributions are of the log normal form, is the following:

$$y = X^a \ell^{-b}$$

where X = time to failure under normal stresses

y = time to failure under accelerated stresses

a and b = parameters of model determined from failure data

Based on the data, the model takes the following form:

$$y = 0.39\sqrt{X}$$

or

$$X = \left(\frac{y}{0.39}\right)^2$$

where X is expressed in terms of age in years and y is expressed in terms of accelerated aging cycles. In this case y is one cycle when the parameters to be used for the accelerated aging cycle are 24, 144, 48, 1.0.

From this graph and the time transformation model, the natural age to which it is desired to age the PFD can be chosen and the corresponding time needed under accelerated conditions selected.

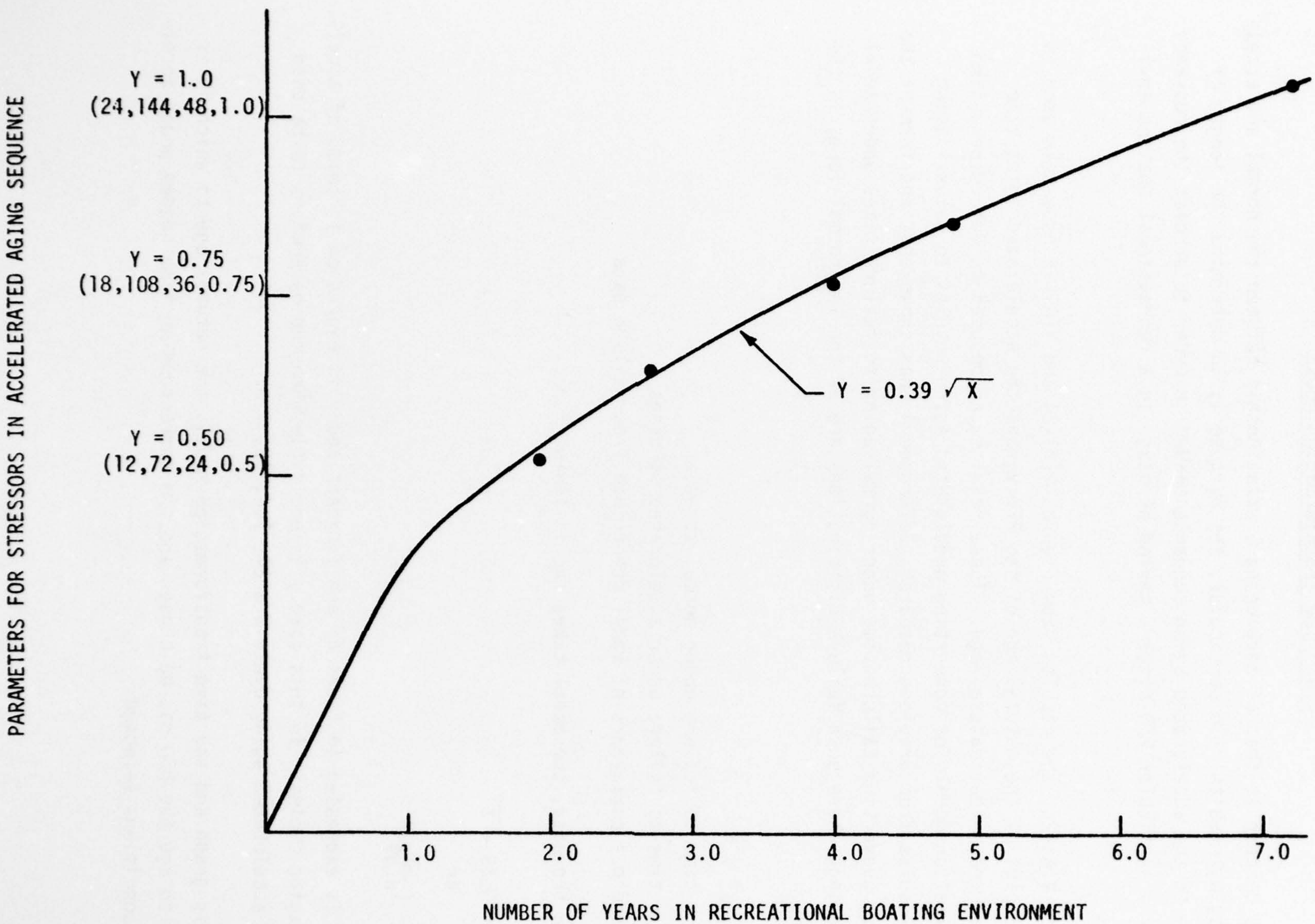


FIGURE V(A)-26. TIME TRANSFORMATION MODEL

4.5 Application of Results

At this point in the development of the accelerated aging model, it was of interest to test this accelerated aging sequence on PFDs made by other manufacturers and using other types of foam. PFDs made by four different manufacturers and using two different foams, polyvinyl chloride and polyethylene, were exposed to approximately 1.6 years of usage under accelerated conditions. The loss of buoyancy was measured and the results are reported below.

	POLYVINYL CHLORIDE FOAM		POLYETHYLENE FOAM	
MANUFACTURER	A	B	C	D
BUOYANCY LOSS (LBS)	2.6	1.5	0.4	0.1

These results show that the use of the accelerated aging sequence would provide a method by which a particular manufacturer's PFD could be evaluated for both, type of foam and type of construction and receive a reliability index indicative of his particular combination. Caution should be exercised in the use of the above results, however, due to the extremely small sample tested.

In addition to the testing of foam PFDs, four kapok PFDs were put through an accelerated aging sequence equivalent to 6.5 years of normal usage. The results showed that these PFDs failed to lose any buoyancy after this exposure.

The aging sequence developed has been an attempt to model as many environmental/usage stressors as possible from a cost, time, and practicality standpoint. The results from the use of this aging procedure have shown that it is capable of detecting latent failure modes (i.e., loss of buoyancy of mechanical failures) in both inherently buoyant and inflatable PFDs (Section V-B). Therefore, the aging procedure appears to be valid in its present form for most types of PFDs. However, since only one type of PFD was collected and used an an environmental/usage model, there is a possibility that an environmental stressor exists which was insignificant in terms of the PVC foam PFDs and the inflatables tested, but which is significant in some other type of PFD. If this environmental stress is found to exist, then it would have to be included in order to form a more

generalized model. A more generalized environmental model would not delete any of the current tests, but would instead include any other tests found to be significant. Even though the accelerated test sequence accurately models the environment, it is possible (though unlikely) that some other environmental factor exists which is significant.

5.0 DETERMINING THE RELIABILITY INDEX

In order to determine the reliabiity index, a series of tests must be performed on the PFDs after they have been aged to determine the probability that a particular PFD will be able to perform its intended function* Obviously, the most important test to be run is on the amount of buoyancy provided by the PFD (long term mission) and the length of time it provides that buoyancy (short term mission). Figure V(A)-27 is a flowchart detailing the step-by-step process that a manufacturer's PFDs would follow in order to obtain a number for the reliability index. This process is broken into two parts:

1. A sample of PFDs is aged to some predetermined number of years. A mean buoyancy is calculated and the corresponding reliability index determined.
2. PFDs from this sample are split into four groups, pass/fail tests on four criteria are performed.

Part one is concerned with determining the reliability index of a particular PFD by measuring and calculating the mean buoyancy after accelerated aging of the PFDs to some predetermined natural age. The reliability index in this case is defined as the percentage of the population that would still be protected by a PFD that has been used for several years in a recreational boating environment (Figure V(A)-28). A minimum requirement could be established designating an acceptable minimum useful life for a manufactured PFD.

Part two consists of four pass/fail tests that will be performed on a fraction of the original sample. In order for a lot to be acceptable, the PFDs must pass each of the four tests.

1. Flame Exposure Test - In considering any PFD reliability tests, the safety of the recreational boater from hazards in addition to loss of buoyancy must be considered. The safety of the boater from a possible fire hazard needs to be assured, since this is a foreseeable danger. For instance, there exists the possibility that during accidental exposure of a PFD to an ignition source, the PFD would catch fire either when worn by a boater or when stowed away.

---

* The possibility of performing the original LSI tests for E_W to determine PFD reliability was considered at this point, but found to be less reliable and accurate than this method.

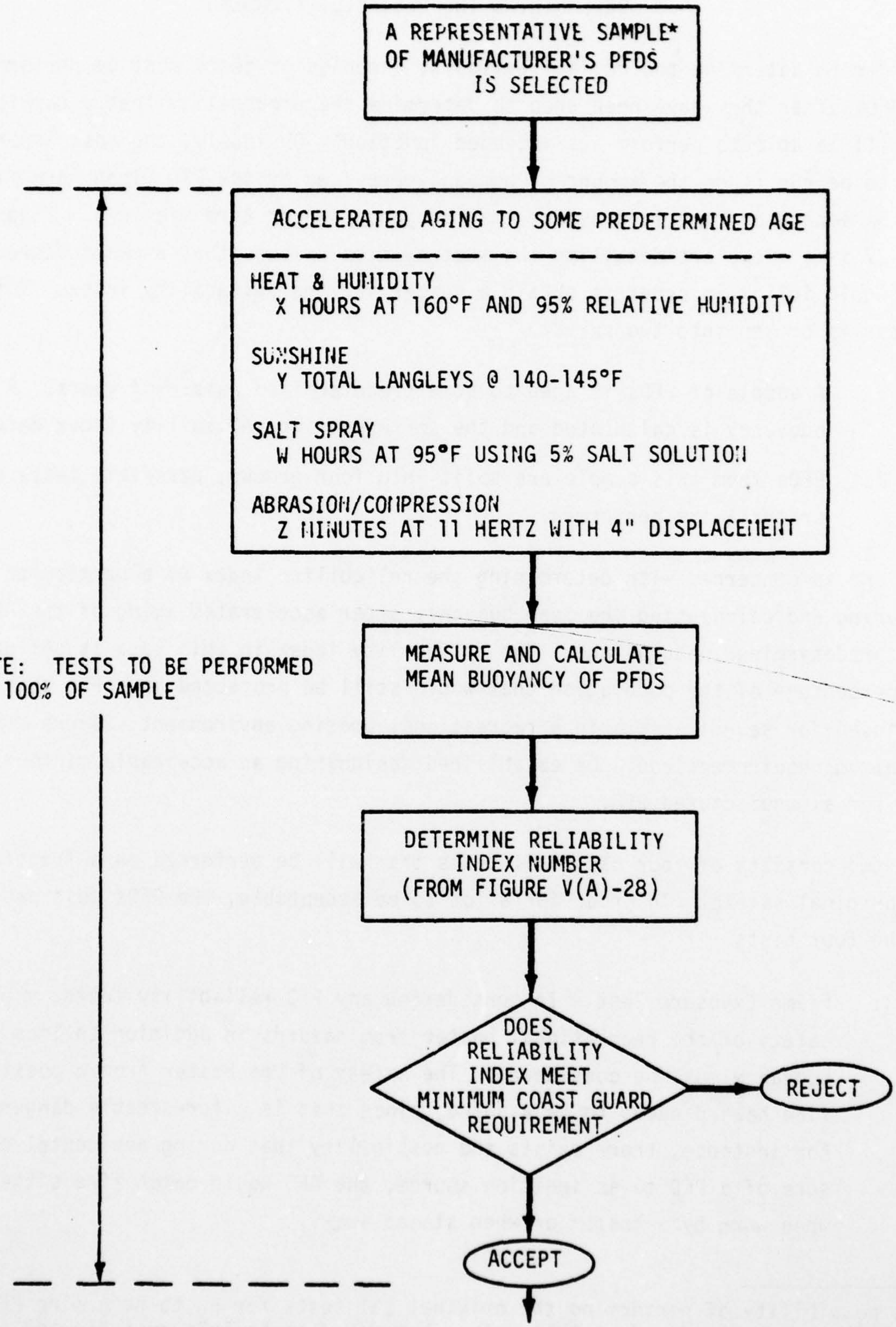


FIGURE V(A)-27. RECOMMENDED TEST PLAN

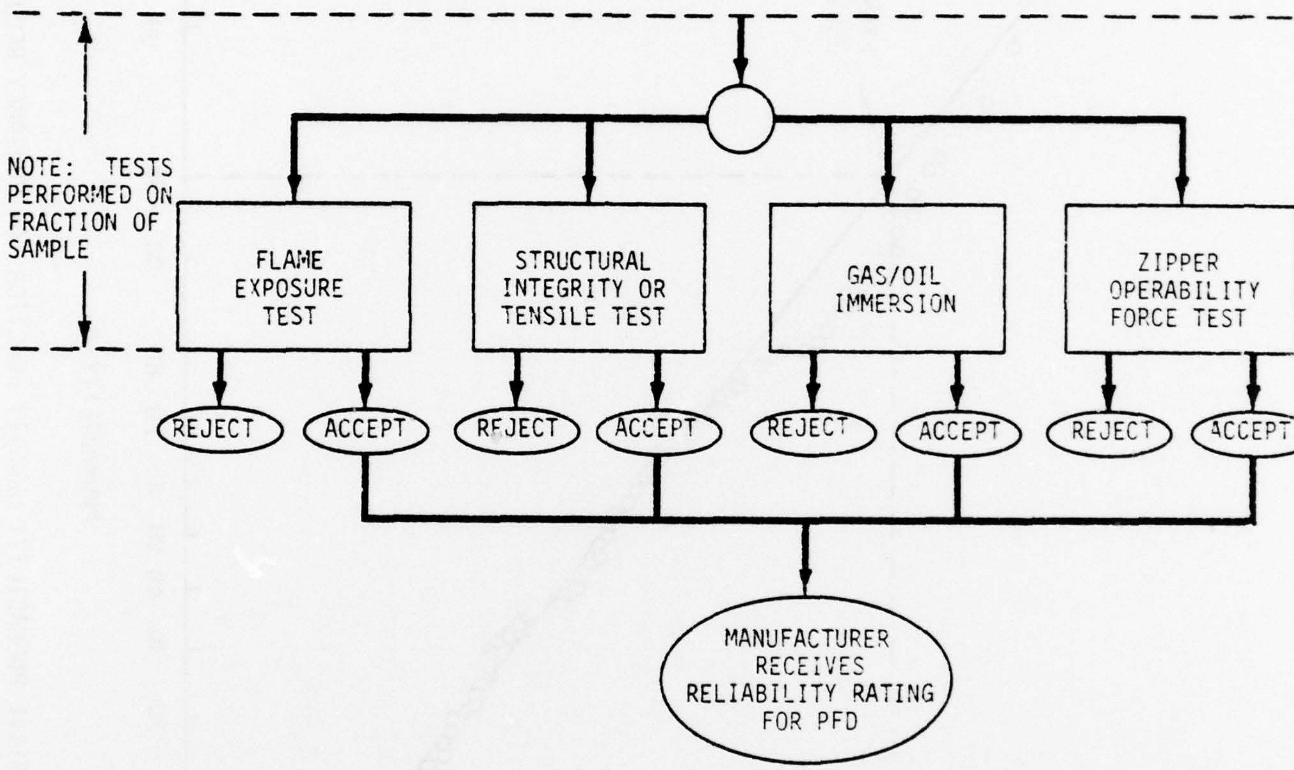


FIGURE V(A)-27. RECOMMENDED TEST PLAN (concluded)

---

* The sample size required depends on the sample variance, level of accuracy desired and the level of risk accepted.

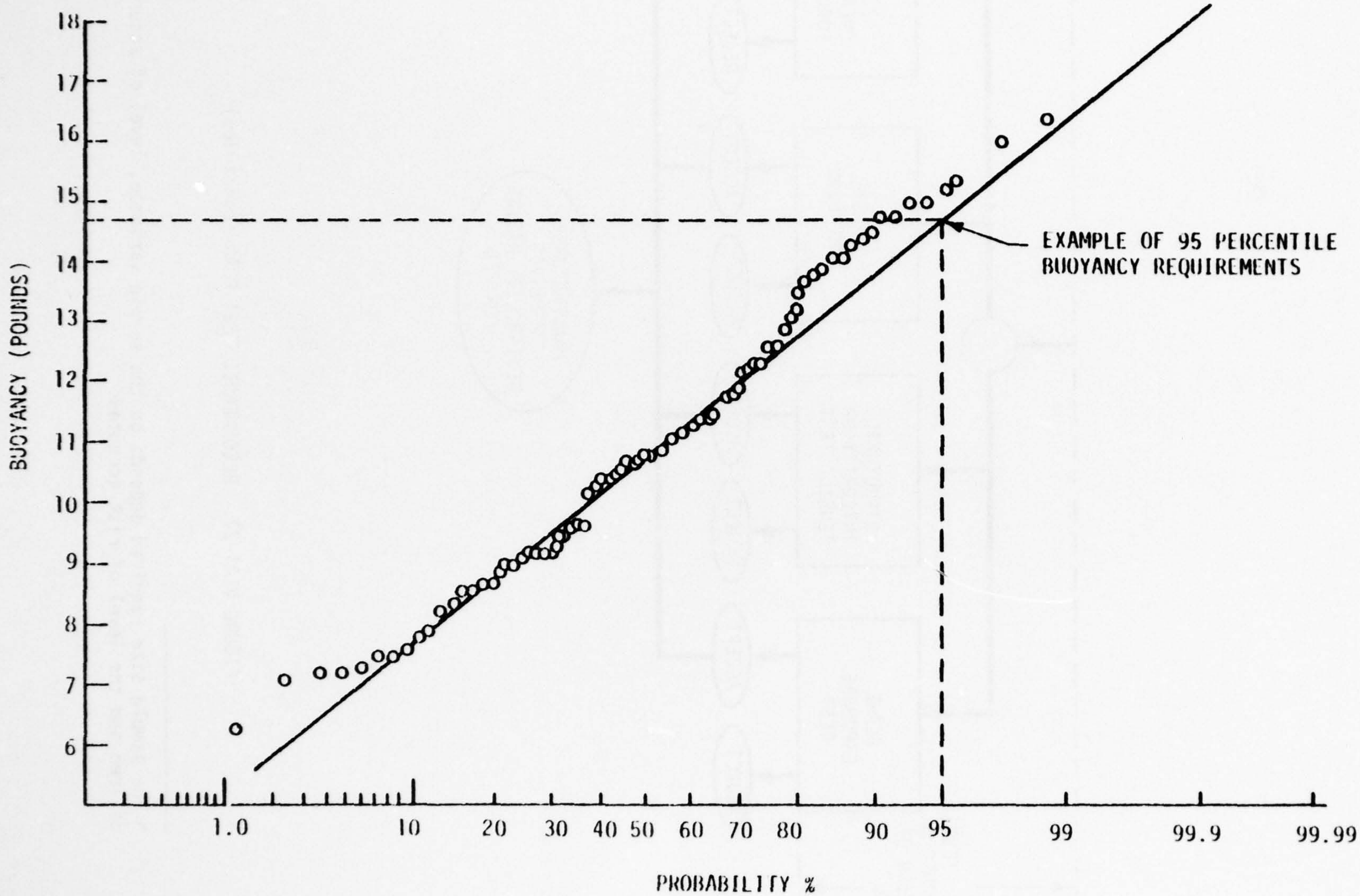


FIGURE V(A)-28. CUMULATIVE PROBABILITY DENSITY FUNCTION FOR BUOYANCY REQUIREMENT

The test plan includes a two-second flame exposure test such as that outlined in UL 1123 in order to insure boaters' safety. Coast Guard research to date has not indicated a need for a test more severe than the two-second flame exposure test.[1]

Additional work is needed to evaluate other fire related hazards to PFDs (such as operator induced stressors) which might become significant if the LSI system is implemented, due to the availability of new types of PFDs and changes in utilization patterns, such as increased wear. One such possible hazard is loss of buoyancy in inflatables and hybrids from cigarette burns.

One alternative considered was a flammability test such as that required for children's sleepwear, draperies in public buildings, and mattresses. The purpose of a flammability test is to insure that the PFD will not support combustion (i.e., that the PFD will be self-extinguishing.

The specifications for such a test would consist of exposure of a PFD held vertically to a lighted match for a period of 12 seconds. The PFD would then be required to self-extinguish within 30 seconds in order to pass the test. Additional specifications would be developed in order to assure a fully controlled test.

Preliminary testing of inherently buoyant PFDs showed that several Type III foam PFDs passed this test; however, a used Type II kapok PFD and one type of inflatable PFD did not meet this requirement (see Figures V(A)-29 and V(A)-30).

2. Structural Integrity or Tensile Strength Test - The main purpose of this test is to insure that the PFD is constructed of and maintains sufficient structural strength to be effective. In order to be effective, the PFD must be of sufficient strength to be maintained in the proper position on the person and provide a means with which to grasp an unconscious person in the water and pull him to safety. The structural integrity test will test for strength in all parts of the PFD (i.e., shoulder strength included).

   The test to be run for tensile strength would consist of requiring a PFD to maintain a 300 lb load for a period of five minutes without showing signs of structural breakdown.

---

[1]Personal communication from CDR Charles Niederman, USCG.

3. Gas/Oil Exposure Test - The purpose of this test is to insure that the PFD will exhibit a minimum level of resistance to an environment consisting of some possible gas and oil exposure.

   This test shall consist of soaking a PFD in a gas/oil mixture of ratio 20 to 1 for an 8 hour period. The PFD should exhibit no more than a 25% loss in buoyancy from the unexposed state.

4. Zipper Operability Force Test - The purpose of this test is to insure that force required to operate the zipper mechanism does not exceed normal human capabilities.

   A gage for measuring maximum pull strength shall be used to determine whether the maximum pull strength of 15 lbs is exceeded. A pull strength of less than 15 lbs would be passed.

These tests represent the minimum number of tests that should be used to determine the reliability of the PFDs and insure that the reliability of the PFDs is maintained for some given life period.

An example of this process could be as follows. If the Coast Guard adopts a standard that a PFD shall support 95% of the population after being used for five years, then a sample of PFDs would be aged for this period of time under the accelerated aging procedure (Figure V(A)-26). The time transformation model gives the following parameters for the accelerated aging sequence:

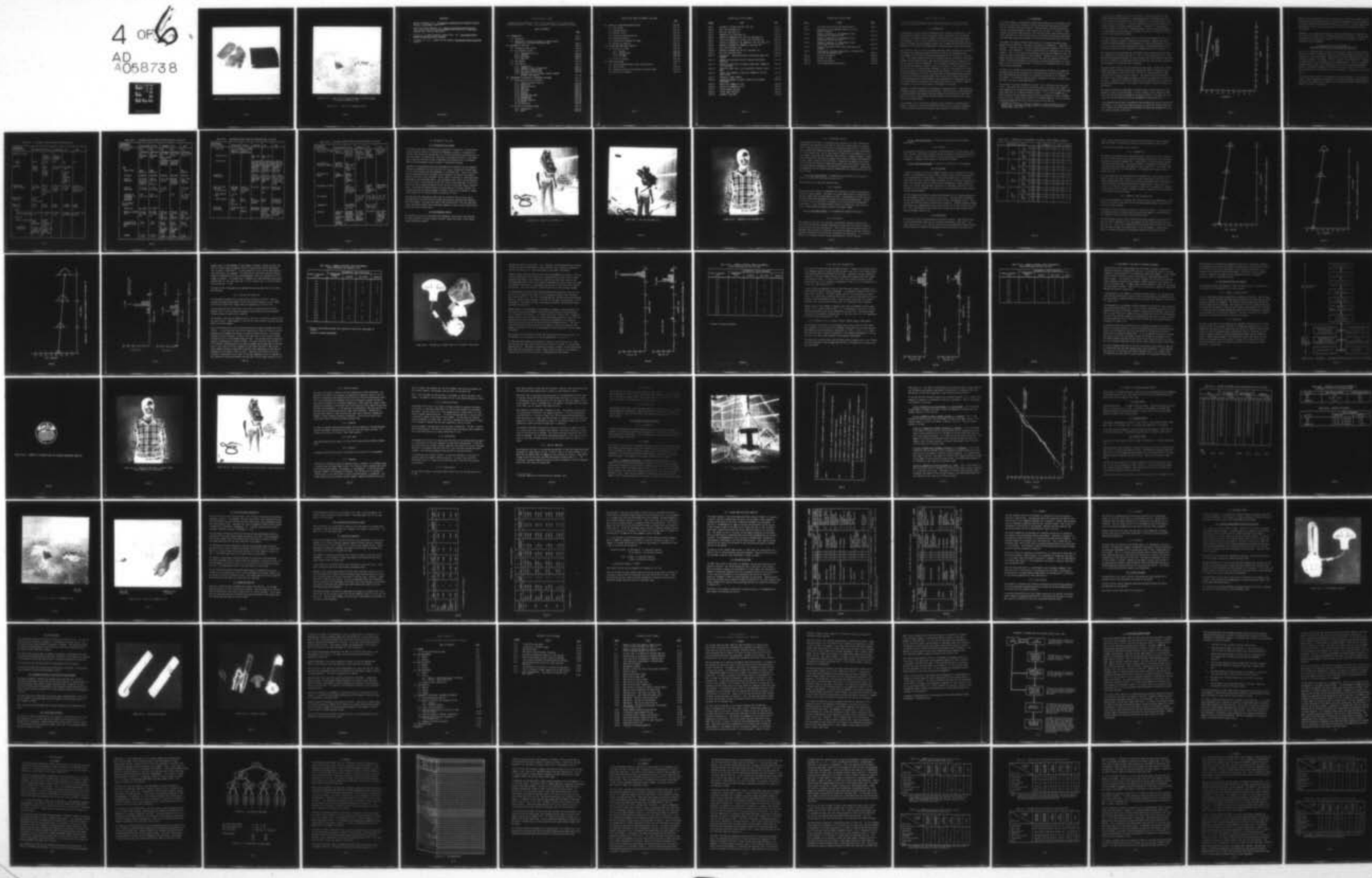
- 21 hours of heat/humidity at 160°F/95% relative humidity
- 126 hours of sunlight or 8845 langleys at 140°-145°F chamber temperature
- 42 hours of salt spray - 95°F and 5% salt solution
- 50 minutes of abrasion/compression at 11 Hz and 0.4 in. displacement

After this exposure, the mean buoyancy of this sample lot is calculated. Using Figure V(A)-28, the reliability index number is determined. The PFD sample is then broken into four groups and the four tests described (Figure V(A)-27) are performed. If the PFDs pass each of the four tests, then minimum reliability standards have been attained. This particular PFD would be assigned the reliability index number determined previously.

RELIABILITY OF PFD = PERCENTAGE OF ADULT POPULATION THAT PFD WOULD SUPPORT AFTER 5 YEARS OF USAGE

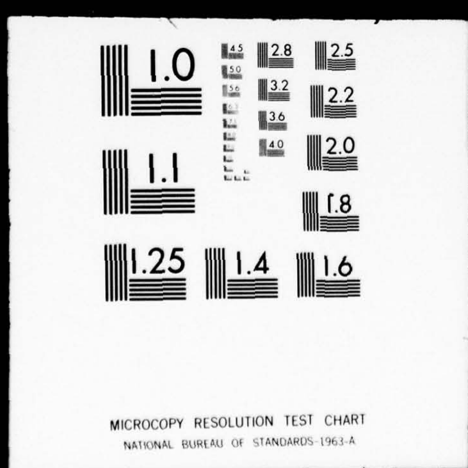
AD-A058 738 WYLE LABS HUNTSVILLE ALA F/G 6/7
PERSONAL FLOTATION DEVICES RESEARCH. VOLUME 2. RESEARCH REPORT.(U)
JAN 78 T DOLL, M PFAUTH, J GLEASON, S COHEN DOT-CG-42333-A
UNCLASSIFIED MSR-78-1-VOL-2 USCG-D-41-78-VOL-2 NL

4 OF 6
AD
A058738



4 OF 6

AD A058738



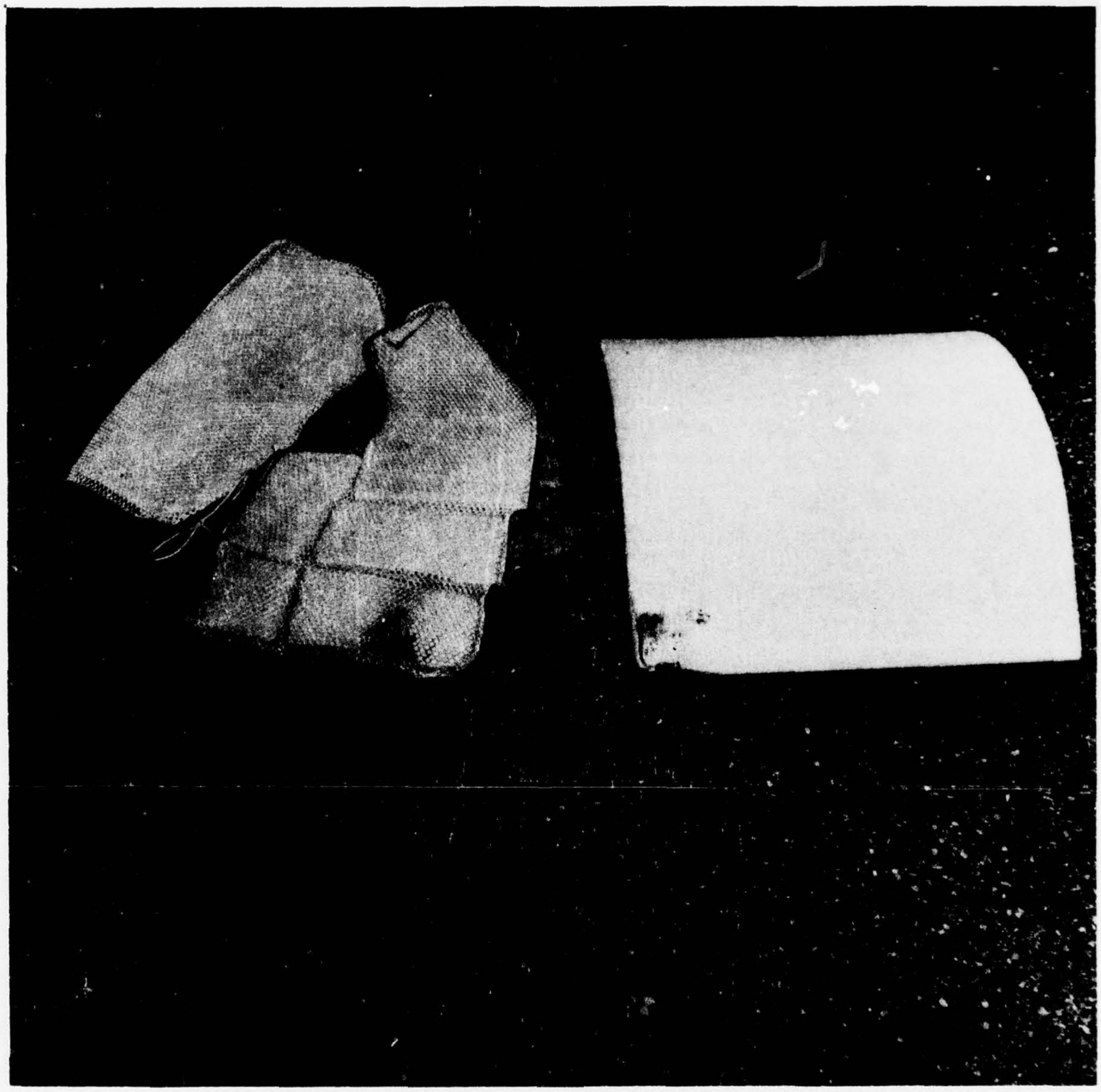


FIGURE V(A)-29. PFD AND FOAM MATERIAL EXPOSED TO ALTERNATE FLAMMABILITY TEST

FIGURE V(A)-30. KAPOK PFD (LEFT) AND INFLATABLE PFD AFTER EXPOSURE TO ALTERNATE FLAMMABILITY TEST

FIGURE V(B)-19. RESULTS OF FLAMMABILITY TEST

REFERENCES

1. Operations Research, Inc., A Reliability Investigation of Personal Flotation Devices - Final Report, August 1973.

2. Booz-Allen Applied Research, Inc., Study of Personnel Flotation Devices, Final Report, Booz-Allen Applied Research, Inc. for the U. S. Coast Guard, November 1968. NTIS No. AD-787-023.

3. Zerlaut, G. A., Desert Sunshine Exposure Tests, Inc., Accelerated Outdoor Weathering Employing Natural Sunshine.

4. Yurkowsky, W., et al., Hughes Aircraft Company, Accelerated Testing Technology, Volume 2.

SECTION V (B)

THE DEVELOPMENT OF A RELIABILITY TESTING METHODOLOGY FOR INFLATABLE AND HYBRID PFDS

TABLE OF CONTENTS

SECTION V(B) TABLE OF CONTENTS, Concluded

SECTION V(B) LIST OF FIGURES

SECTION V(B) LIST OF TABLES

SECTION V (B)

THE DEVELOPMENT OF A RELIABILITY TESTING METHODOLOGY FOR INFLATABLE AND HYBRID PFDS

1.0 INTRODUCTION

In the analysis of the reliability methodology for inherently buoyant PFDs, it was shown that the effects of the recreational boating environment could be modeled effectively for certain types of inherently buoyant PFDs by an Accelerated Aging Test Sequence. This showed the feasibility of using an Accelerated Aging Test to properly reproduce the environmental factors and to induce the same type of failure mechanisms in the PFDs as are experienced in the recreational boating environment.

The reliability analysis of the inflatable and hybrid PFDs required that the modeled environment from inherently buoyant reliability research be supplemented with environmental factors which are uniquely detrimental to the reliability of inflatables. This necessitated an analysis of problems unique to inflatables, which were gleened from the specifications, test results and usage results of organizations who are current users of inflatables. This information proved helpful but did not define those environmental factors to which an inflatable is most susceptible. A Reliability Test Plan therefore was developed to test the susceptibility of inflatables to extremes of the recreational boating environment. The results of inflatable PFDs subjected to this test plan showed that an accelerated testing technique is feasible for testing inflatable PFDs, that latent failure modes, which were either manufacturing or design problems, were transformed into detectable failures by the environmental stresses and that the state-of-the-art for selected types of inflatables is such that these types of inflatables are reliable.

Therefore, an Accelerated Aging Test Sequence was developed which is applicable to inherently buoyant, inflatable and hybrid PFDs. The test results of PFDs subjected to the Accelerated Test Sequence are then inserted into a Reliability Prediction Model to arrive at a Reliability Index which can be used to compare styles, safety features and manufacturers.

Also included in this section are estimates of the reliability of those devices tested, an analysis of the failure modes and effects, which is used to recommend actions to minimize these failure modes, and an analysis of inflation systems.

1.1 Background

In trying to develop a performance oriented test methodology for inflatables, which results in a reliability prediction, those organizations associated with current uses of inflatable PFDs were contacted. Those contacted included manufacturers, airlines, foreign governments, diver associations, and the U. S. Military. After reviewing the various specifications, tests and test results which were available, it was concluded that none have the ability of providing a Reliability Prediction. There were many subjective estimates of reliability which varied from low to high.

For example, the Federal Aviation Administration has issued an Aerospace Recommended Practice, ARP 1354, "Individual Inflatable Life Preservers." Compliance is voluntary. The FAA has also set forth minimum performance standards in the form of TSO-C13c, "Life Preservers," to which the manufacturer is obligated to certify conformance. The air lines have various methods of assuring the integrity of the life jackets on board which conform to these standards. However, due to a lack of documented analyses of these methods and the fact that the life jackets are normally stored in a benign environment, not indicative of recreational boating, such information is not a sufficient predictor of reliability of inflatable PFDs in a recreational boating environment.

The quality of a PFD may be sufficiently established by the tests and inspections performed during and at the conclusion of manufacturing, but unless specific test plans have been devised to predict the functioning of the PFD in its intended environment, it is possible that the quality throughout its useful life may not be the same as the quality when manufactured.

The attribute of quality throughout its useful life is defined by the term reliability. The classic definition of reliability and the one used in this report is "the probability of a product performing without failure a specified function under given conditions for a specified period of time."* It is all too common for an item to conform with the product specification (as evidenced by a test of conformance) to fail at a latter date to perform its intended function. This is the basic difference between manufacturing quality control and reliability.

* "Reliability of Military Electronic Equipment," report by Advisory Group on Reliability of Electronic Equipment, Office of the Assistant Secretary of Defense (R&D), June, 1957.

In the context of reliability used in this report, a failure to perform a PFD's intended function may be caused by a design deficiency or a manufacturing error. From the aspect of the intended user, the difference is of no significance. That is also true for this report. A failure is defined as a PFD failing to perform its intended function of providing adequate buoyancy. Therefore, all testing was designed to detect all failures: those designated as quality control problems and those designated as design problems, throughout the research, development, design, prototype, and manufacturing process.

Like many items sold to the general public, no disciplined approach has been followed which yields a reliability estimate for the product. However, more manufacturers are becoming aware of the importance of a disciplined approach to reliability as an aid in minimizing warranty and product liability exposure as well as providing a product which will perform its intended function for its useful life.

The closest any of the organizations investigated came to having applicable objective evidence of reliability was the U. S. Navy. It was found that the U. S. Navy does have a maintenance procedure for the inflatable PFDs used by Navy aircrews and that this procedure is followed and records are kept which can be used to ascertain the performance in the Navy-aircraft environment.

The results which the U.S. Navy has achieved are very good. The Naval Air Systems Command provided information based upon approximately 200,000 inspections over a fifteen month period, from 7/75 to 9/76. During this time, approximately 3340 inflatable PFDs failed to function properly. They were then either repaired or discarded so that the maintenance procedure returned only operational PFDs to the air crews. Figure V(B)-1 shows the reliability of the Navy PFDs which results from the Navy maintenance program. Also shown is the reliability function assuming no maintenance.

Data were not available on the details of each failure so that trends of failure mechanisms could not be established. The data, however, show a constant failure rate with time which does not depend on the age of the PFD. This means that only chance failures are occurring which are independent of accumulated life.

The maintenance results were discussed with Navy personnel who actually perform the maintenance. Their opinion was that there were no significant failure trends and that a portion of the failures were attributable to faulty maintenance which actually created problems or failures.

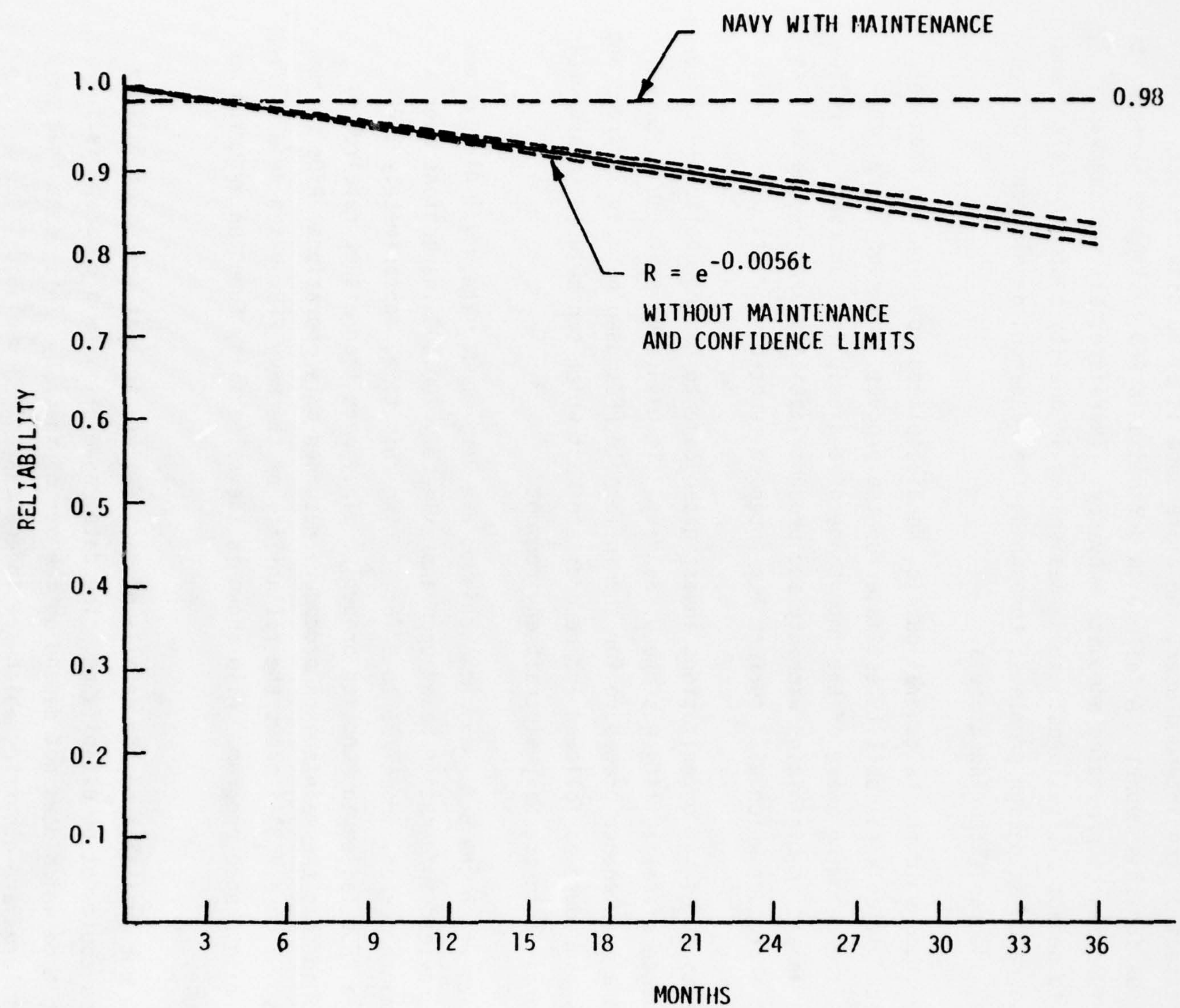


FIGURE V(B)-1. RELIABILITY ESTIMATE FOR NAVY TYPE PFDS

Because of the chance nature of the failures and the different environment to which the Navy PFDs were subjected (most Navy personnel considered the Navy environment to be more harsh than the recreational boating environment), it was not known which environmental factors could or would cause failures in the recreational boating environment.

Therefore, it was necessary to develop a unique test methodology for determining the reliability of PFDs used in a recreational boating environment. The Navy data proved helpful by establishing some base lines to which the results of the new methodology could be compared.

1.2 Comparison of Existing Standards or Specifications Pertaining to Inflatable and Hybrid PFDs

Table V(B)-1 delineates the individual inflatable and/or hybrid PFD specifications which are currently in effect for Australia - Australian Standard 1512-1973, "Life Jackets"; for the United Kingdom - BS3595:1969, "British Standard Specification for Life-Saving Jackets"; for Canada - 65-GP-11, October 1972, "Standard For: Personal Flotation Devices"; for the Federal Aviation Administration - TSO-C13C, "Technical Standard Order, Subject: Life Preservers" and ARP 1354, "Aerospace Recommended Practice, Individual Inflatable Life Preservers"; and for Naval Aviation Crew - MIL-L-81787A(AS), Military Specification, Life Preserver, Inflatable, Utility, Type LPP-1A.

The purpose of this section is to compare the existing standards. With the cognizance of those standards, test methods can be compared, evaluated, standardized, or modified so that optimal use is made of existing performance test methods and the need for new tests is minimized.

TABLE V(B)-1. INFLATABLE AND/OR HYBRID PFD SPECIFICATIONS

PERFORMANCE SPECIFICATION	AUSTRALIAN	BRITISH	CANADIAN	FAA	NAVY
BUOYANCY (POUNDS)		TOTAL/ INHERENTLY BUOYANT	TOTAL/ INHERENTLY BUOYANT		
ADULT	19.56	35/13.5	29/9	35	29
CHILD	11	20/10		25	
RIGHTING	BREAST STROKE - 10 SEC.	FRONT FALL - 5 SEC., BREAST STROKE - 5 SEC.	FACE DOWN 10 SEC.	FACE DOWN 5 SEC. FACE UP FALLS BACK, SWIMS ON SIDE, SWIMS ON BACK	-
FABRICATION BURST STRENGTH	2.9 psi W/O BURST-ING	BURST @ >6 psi EACH TESTED AT 3 psi - 1 MIN.	TESTED AT 10 psi- 60-90°F 5 MIN.	TESTED AT 10 psi - 5 MIN.	TESTED AT 5 psi-10 min. MIN. 4.5 psi AFTER TEST
RESISTANCE TO PUNCTURE	MEDIUM PEN - 6.74 POUNDS	-	-	-	-
MEANS FOR INFLATION	MANUAL & ORAL	MANUAL & ORAL	MANUAL & ORAL	2 MANUAL & 2 ORAL	MANUAL & ORAL
MANUAL					
EASE OF OPERATION	14.6 POUNDS	15 POUNDS	15 POUNDS	15 POUNDS	12 POUNDS MAX.
RATE OF INFLATION	5 sec.	5 sec.	5 sec.	UNSPECIFIED	30 sec.
AUTOMATIC					
RATE OF INFLATION	5 sec. AFTER IMMERSION	OPERATE 5 sec. DISCHARGE 5 sec.	-	-	-
INADVERTENT OPERATION	15 min. 12 POSITION CHAMBER 220 LITRE/ HR	15 min. 12 POSITION CHAMBER 225 LITRE/ HR			

TABLE V(B)-1. INFLATABLE AND/OR HYBRID PFD SPECIFICATIONS, Continued

PERFORMANCE SPECIFICATION	AUSTRALIAN	BRITISH	CANADIAN	FAA	NAVY
CYLINDER	CO_2, EXPENDABLE OR RECHARGE-ABLE	CO_2, EXPENDABLE OR RECHARGE-ABLE	CO_2, EXPENDABLE MIL-C-601 OR MIL-C-25369 TYPE II ALTERNATES COULD BE APPROVED	CO_2 EXPENDABLE MIL-C-601 TYPE I ALTERNATES COULD BE APPROVED	CO_2, EXPENDABLE MIL-C-25369B TYPE II
ORAL					
MOUTH PIECE	NON-METALLIC	NON-METALLIC	-	-	NON-METALLIC
OPTIONAL?	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED
EASE OF OPERATION	NOT OPEN 0.07 psi, OPENED AT 0.36 psi	OPEN AT 0.07 psi to 0.36 psi	FULLY OPEN 0.6 psi	MAXIMUM OPENING PRESSURE 0.6 psi	FULLY OPEN AFTER PRESSING
RATE OF INFLATION	@ 10 psi 3 ft^3/min	@ 1 psi 3 ft^3/min.	@ 1 psi 1.7 ft^3/ min.	-	@ 0.5 psi 1.7 ft^3/ min.
STRENGTH OF ATTACHMENT OF INFLATION MECHANISM	100# FOR 5 min.	100# FOR 5 min.	-	250#	75# FOR 30 SEC. FOR 3 CYCLES
GAS CYLINDERS TESTING					
SHOCK TEST	20' DROP	20' DROP	-	-	
MATERIAL PROVING TEST	FAILURE AT >5950 psi	FAILURE AT >6500 psi	7000 psi W/O FAIL-URE 8000 psi TYPE III	7000 psi W/O FAIL-URE 8000 psi TYPE III	8000 psi W/O FAIL-URE @70°F + 2°F FOR 5 SEC.
FILLING RATIO/ WEIGHING TOLER-ANCE	< 68% ± 1 g	< 68% ± 1 g	MIL-C-25369B 72 - I 76 - II TOLERANCE RANGES GIVEN	MIL-C-25369B 72% - I 76% - II TOLERANCE RANGES GIVEN	MIL-C-25369B II → 76%
LEAKAGE	21 DAYS < 0.1 g	21 DAYS < 0.1 g	2 MIN. H_2O/20" Hg	2 MIN. H_2O/20" Hg	2 MIN. H_2O/20" Hg

TABLE V(B)-1. INFLATABLE AND/OR HYBRID PFD SPECIFICATIONS, Continued

PERFORMANCE SPECIFICATION	AUSTRALIAN	BRITISH	CANADIAN	FAA	NAVY
SAFE LIFE	10 yrs FROM DATE OF MANUFACTURE	10 yrs FROM DATE OF MANUFACTURE	-	-	-
PUNCTURE TEST	-	-	MAX. LOAD 15#	MAX. LOAD 15#	-
RUPTURE TEST	-	-	USE GRADUAL HEATING. NO SPLINTERING FRAGMENTATION OR FAILURE AT WELD CAP	USE GRADUAL HEATING. NO SPLINTERING FRAGMENTATION OR FAILURE AT WELD CAP	USE GRADUAL HEATING. NO SPLINTERING FRAGMENTATION OR FAILURE AT WELD CAP
ELEVATED TEMPERATURE	- -	- -	160±5°F FOR 30 MIN. REWEIGHED AFTER 24 HRS	160°±5°F FOR 30 MIN. REWEIGHED AFTER 24 HRS	CYCLE LEAKAGE 2 CYCLES: 160°±2°F FOR 2 HRS THEN -63°±2°F FOR 2 HRS
WEBBING, TAPES AND CORDS SPECIFICATION	BREAKING STRENGTH > 292#	LIST OF MATERIALS IS EVALUATED	4-GP-105	MIL-W-530 TYPE II 230#	MATERIALS SPECIFIED
WIDTH AGAINST BODY	> 25 mm (1")	-	-		-
SEAM STRENGTH	198# 5 MIN. - 90° ROTATION	600# 15 SEC.	80% of MTL BEING JOINED	MIL-B-5540	SUBJECTED TO PRESSURE OF 5.0 psi
CORROSION RESISTANCE	AUSTRALIAN SPECS	SALT 5% / H_2O/OIL	CORROSION RESISTANT	CORROSION RESISTANT OR PROTECTED SALT SPRAY 5% 100 hr	SOME PARTS SUBJECTED TO 96-100 hrs OF SALT SPRAY @ 5% SALTS

TABLE V(B)-1. INFLATABLE AND/OR HYBRID PFD SPECIFICATIONS, Concluded

PERFORMANCE SPECIFICATION	AUSTRALIAN	BRITISH	CANADIAN	FAA	NAVY
RESISTANCE TO HEAT	60°+2°C FOR 168 hr	60°C FOR FOR 12 hr INFLATED TO 3 psi	60°+3°C FOR 168 hr STABILIZE 12 hr Δ BUOYANCY < 6%	MOLDED NON-METALLIC CAPABLE OF 160°F	SOME PARTS TESTED TO +160°F
RESISTANCE TO PETROLEUM PRODUCTS	KEROSENE FOR 8 hr, DRY 48 hr	H_2O 1/8" depth LIGHT DIESEL OIL 3 hrs	-	-	-
RESISTANCE TO FLAME	"LOW FLAMMABIL-ITY"	OUTER SURFACE - NOT OF HIGH FLAMMABIL-ITY	-	-	-
RESISTANCE TO COLD	-	-10°C FOR 12 hr WITHIN 90 SEC INFLATE TO 3 psi	-	MOLDED NON-METALLIC CAPABLE OF -65°F	SOME PARTS SUBJECTED TO -65°F
PFD LEAKAGE	-	-	2 psi FOR > 24 hr; 1.5 psi min.	2 psi FOR 12 hr LOSS < 0.5 psi	2 psi FOR 4 hr, 1.6 psi min.
PERMEABILITY	-	NO BUBBLES 4 psi, BS-2-F-100	-	He < 5 l/m^2 FOR 24 hrs @77°F MAX.	-
BUOYANCY	CAGE SUB-MERGED > 5 cm BELOW H_2O, AFTER 24 hr BUOYANCY MEASURED	BUOYANCY MEASURED BELOW H_2O SURFACE FOR 6 hr, REMEASURED	IN CAGE 2" BELOW H_2O SUR-FACE, BUOYANCY MEASURED	NO DETAILS	29# WEIGHT WILL NOT COMPLETELY SUBMERGE LIFE PRE-SERVER, 73±5°F

2.0 RELIABILITY TEST PLAN

2.1 Introduction and Purpose

Since the current users, manufacturers or approvers of commercial inflatable PFDs did not have any data which related PFD performance to actual or simulated conditions, and the results from the Navy air crew PFD maintenance program were not in sufficient detail to identify any significant environmental factors, it was necessary to perform a series of tests to determine the susceptibility of inflatable PFDs to the environmental factors present in recreational boating.

Therefore, an experimental design was developed to test whether the environmental stresses of temperature cycling, sunshine, salt spray, and abrasion offered potential as stress inducing failure mechanisms in inflatable PFDs. Since it was important to determine potential stresses and not necessary to identify the specific amount or duration of any individual stress, tests of statistical significance were performed at low confidence levels. Low confidence levels tend to allow the possibility of error in the direction of calling a stress significant when in reality it may not be and to reduce the possibility of calling a significant stress insignificant. Also since the absolute level of stresses was not of primary concern, all stresses were used at either extremes in excess of what would be normal in recreational boating or for durations which are atypical or both.

The test plan was conducted on three types of inflatable PFDs currently being manufactured so that the variability among manufacturing techniques and materials could be studied. The types consisted of PFDs manufactured to military specifications, FAA specifications, and unregulated commercial practice (see Figures V(B)-2, V(B)3 and V(B)-4, respectively).

2.2 Environmental Factors

The reliability test plan consisted of environmental factors which were selected for their potential to cause stresses and their common occurrence in the recreational boating environment.

FIGURE V(B)-2. NAVY TYPE INFLATABLE PFD

FIGURE V(B)-3. FAA TYPE INFLATABLE PFD

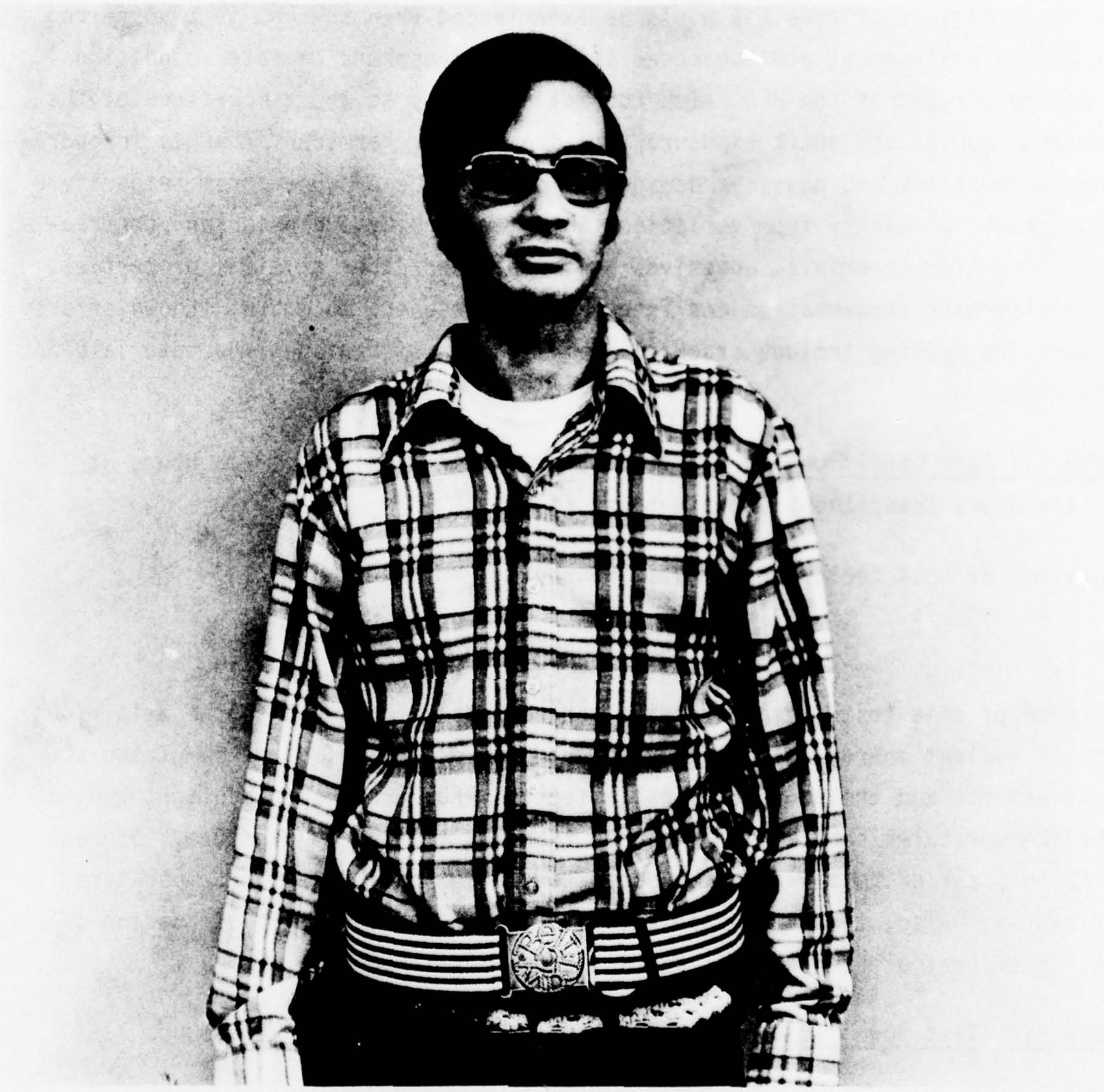


FIGURE V(B)-4. COMMERCIAL TYPE INFLATABLE PFD

2.2.1 Temperature Cycling

The purpose of this test is to determine the resistance of a PFD to the shock of repeated surface exposures to extremes of high and low temperatures for comparatively short periods of time (as would be experienced when the PFD is transferred from a heated environment and subjected to a cold atmosphere or water conditions). It is not required that the PFD reach thermal stability at the temperature of the test chamber during the short exposure time specified. Permanent changes in operating characteristics and physical damage, which could be produced from temperature cycling, result primarily from variations in dimensions by expansion and contraction of dissimilar materials, adhesives and metals and other physical properties, and from alternate condensation and freezing of atmosphere moisture. Known effects of temperature cycling include cracking, delamination of finishes and materials and seal failures.

2.2.1.1 Test Specification - A temperature cycle consists of six hours at 160°F, six hours transition, and six hours at 0°F.

The duration of this test was 168 total hours.

2.2.2 Sunshine

The purpose of this test is to determine the resistance of a PFD to the deletrious effects of radiant energy. The effects of radiant energy which are simulated are the heat effects and the photo-chemical effects. PFDs exposed to sunlight can have internal temperatures substantially higher than the ambient temperature. Storage of a PFD in a car or boat which is exposed to the sun can raise the temperature significantly. Also, the photo-chemical effects of sunshine may cause fading of colors, deterioration of plastics, fabrics and natural rubber.

2.2.2.1 Test Specification - 1.52 Langleys per minute for 240 hours.

2.2.3 Salt Spray

The purpose of this test is to provide an accelerated laboratory corrosion test simulating the effects of seacoast atmospheres on metals with or without protective coatings and on the other PFD materials. Passing this test satisfactorily does not guarantee that the metals or materials will prove satisfactory under any corrosive condition including so called "marine" atmospheres and ocean water. It is especially helpful as a screening test for revealing particularly inferior coatings.

2.2.3.1 Test Specification - 5% salts for 168 hours, per MIL-STD-810C, Method 509.1.

2.2.4 Abrasion

The purpose of this test is to provide an accelerated test to simulate wear, abrasion, vibration, and impact to which a PFD may be subject in actual use conditions. To do this, a weight is distributed over the surface area of the PFD while it is vibrated at a frequency which causes the PFD weight to bounce.

2.2.4.1 Test Specifications - 2 hours @ 11 Hz and 0.41 in. displacement.

2.3 Test Method

In order to evaluate all four environmental factors and all combinations of these factors, it was necessary to have sixteen different conditions which represent all of the combinations of these factors. Table V(B)-2 depicts all of the sixteen states and also gives a serial number assignment for all of the PFDs tested to this plan. Only one type of PFD per condition was used because of budget constraints, except for the Navy type PFDs which, because of an additional constraint on the availability of CO_2 cylinders, was used only in the conditions which were selected as being the most severe.

All PFDs tested were tested for operation and buoyancy prior to being subjected to the environmental factors specified in Table V(B)-2. The tests were performed to the previously mentioned test specifications for each environmental factor. After testing, each PFD was tested for operation and buoyancy. The PFDs remained inflated and buoyancy was rechecked after each 24 hour period for at least 72 hours for each PFD. Also, some PFDs were stored under water between the 24 hour buoyancy tests and the remainder stored in air.

2.4 Test Results

The Reliability Test Plan generated many noteworthy results. Some findings aided in simplifying further tests and also defined some problems in the tests. Two major results were: first, that an accelerated testing technique is feasible since certain types of inflatable PFDs degraded during the Reliability Test Plan; and

TABLE V(B)-2. COMBINATION OF ENVIRONMENTAL FACTORS VS. SERIAL NUMBER ASSIGNMENT

ENVIRONMENTAL FACTORS				COMMERCIAL	FAA	NAVY
Abrasion	Salt Spray	Temp. Cycle	Sun	2L	7	11
			No Sun	1L	2	15
		No Temp. Cycle	Sun	5S	11	8
			No Sun	2M	16	14
	No Salt Spray	Temp. Cycle	Sun	1S	9	
			No Sun	3X	4	
		No Temp. Cycle	Sun	3L	8	
			No Sun	3M	3	3
No Abrasion	Salt Spray	Temp. Cycle	Sun	1M	1	6
			No Sun	3S	10	13
		No Temp. Cycle	Sun	2S	12	2
			No Sun	4S	14	1
	No Salt Spray	Temp. Cycle	Sun	1X	13	
			No Sun	6S	15	
		No Temp. Cycle	Sun	2X	6	
			No Sun	7X	5	

second, latent failure modes which were either manufacturing or design problems were transformed into detectable failures by the environmental stress factors.

A listing of the important results follows:

2.4.1 Permeability

The buoyancy measurements which were made on the inflatable PFDs prior to undergoing any testings shows that all subject inflatables lose buoyancy over time due to the physical process of permeability. Figures V(B)-5, V(B)-6, and V(B)-7 exhibit the rate at which buoyancy is lost after the PFD is inflated due to permeability for the FAA type, Navy type, and commercial type, respectively. All subject PFDs used carbon dioxide as the inflation gas. The average rate of buoyancy loss is linear with time.

It is concluded that any specification for inflatable PFDs should account for permeability and in this case, since it is a linear relationship, only the initial buoyancy measurement after inflation and end point measurement after some period of time is necessary for determining the rate of buoyancy loss. Also, since the variability of the rate of loss of buoyancy is small due to permeability, losses of buoyancy due to leaks is readily apparent; therefore, separate tests for permeability and leakage are not necessary.

2.4.2 Commercial Type Inflatable PFD

Of the sixteen commercial inflatable PFDs tested to the various combinations in the Test Plan, one had a catastropic failure and the remainder showed a statistically significant lower buoyancy.

The symptom of the catastropic failure was a failure to inflate. A failure analysis determined that the cause of the failure was misalignment of the piercing pin with respect to the area to be pierced on the cylinder.

The mean buoyancy 24 hours after inflation after being subjected to the Test Plan was 14.32 lbs as compared to 15.91 lbs buoyancy 24 hours after inflation prior to the Test Plan. The 14.32 lb average does not include the PFD which did not inflate. With that one included, the average drops to 13.4 lbs buoyancy. Figure V(B)-8 shows the frequency diagrams of the buoyancy before and after the Test Plan.

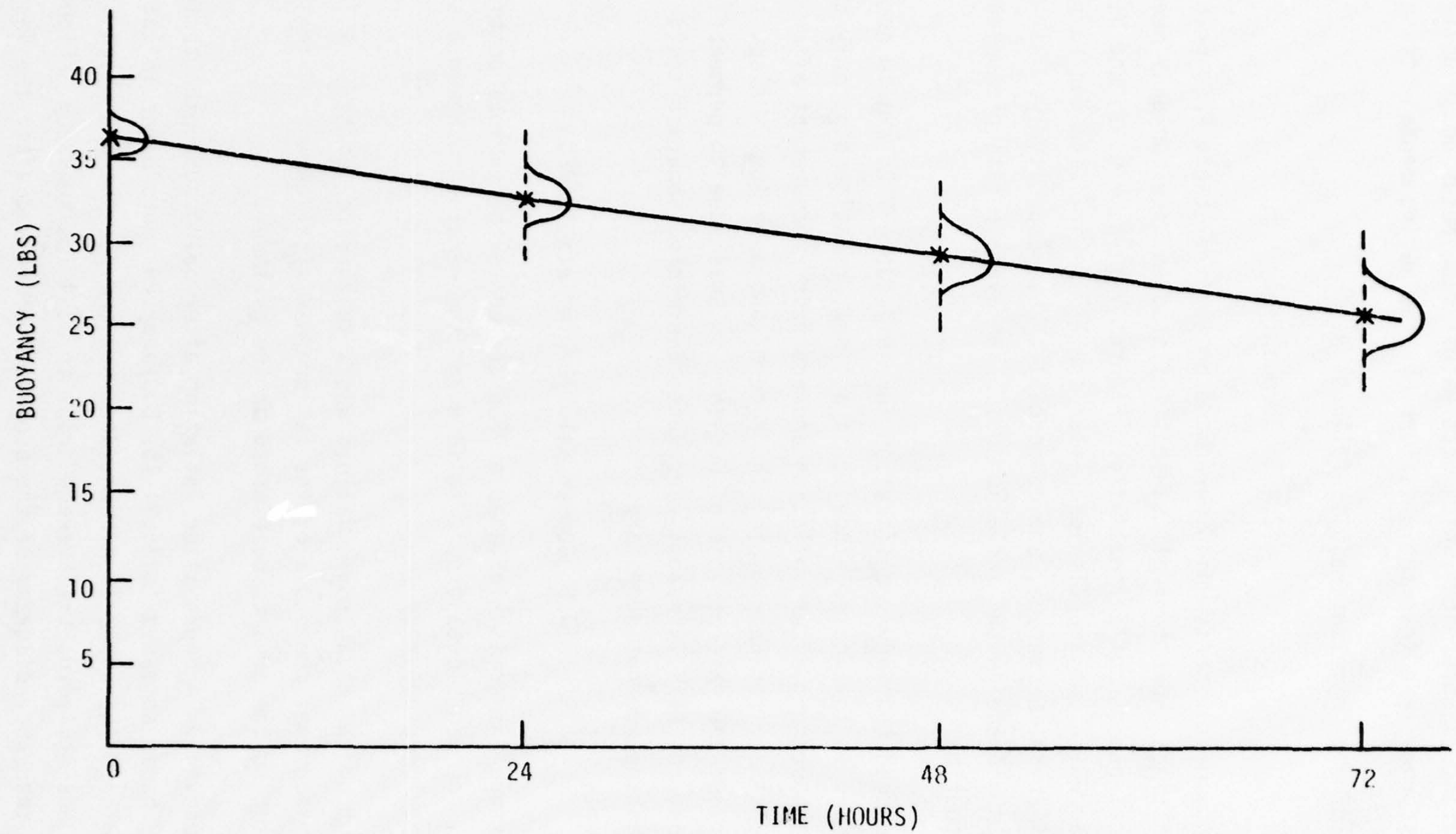


FIGURE V(B)-5. EFFECTS OF PERMEABILITY ON FAA TYPE INFLATABLE PFD

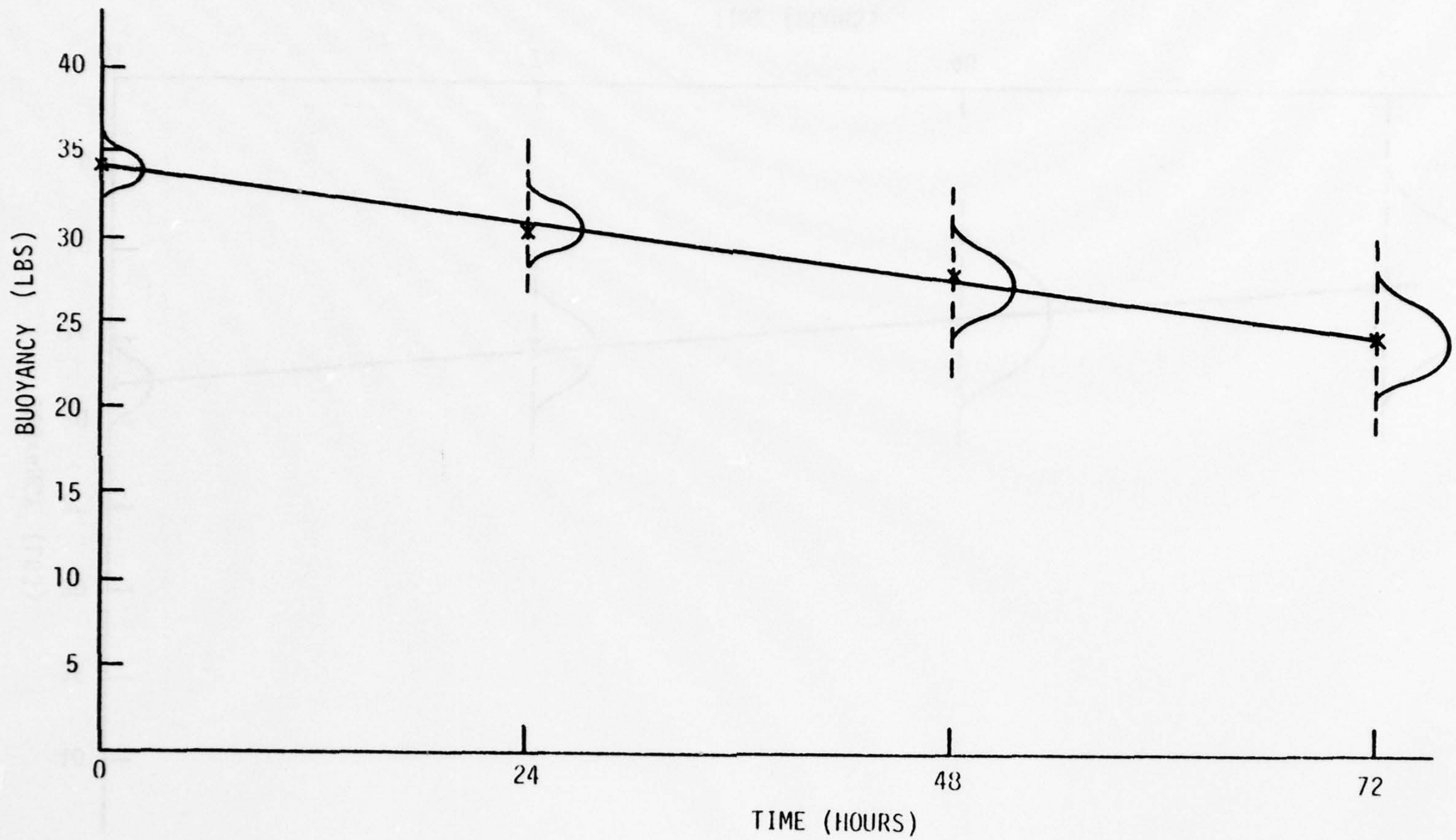


FIGURE V(B)-6. EFFECTS OF PERMEABILITY ON NAVY TYPE INFLATABLE PFD

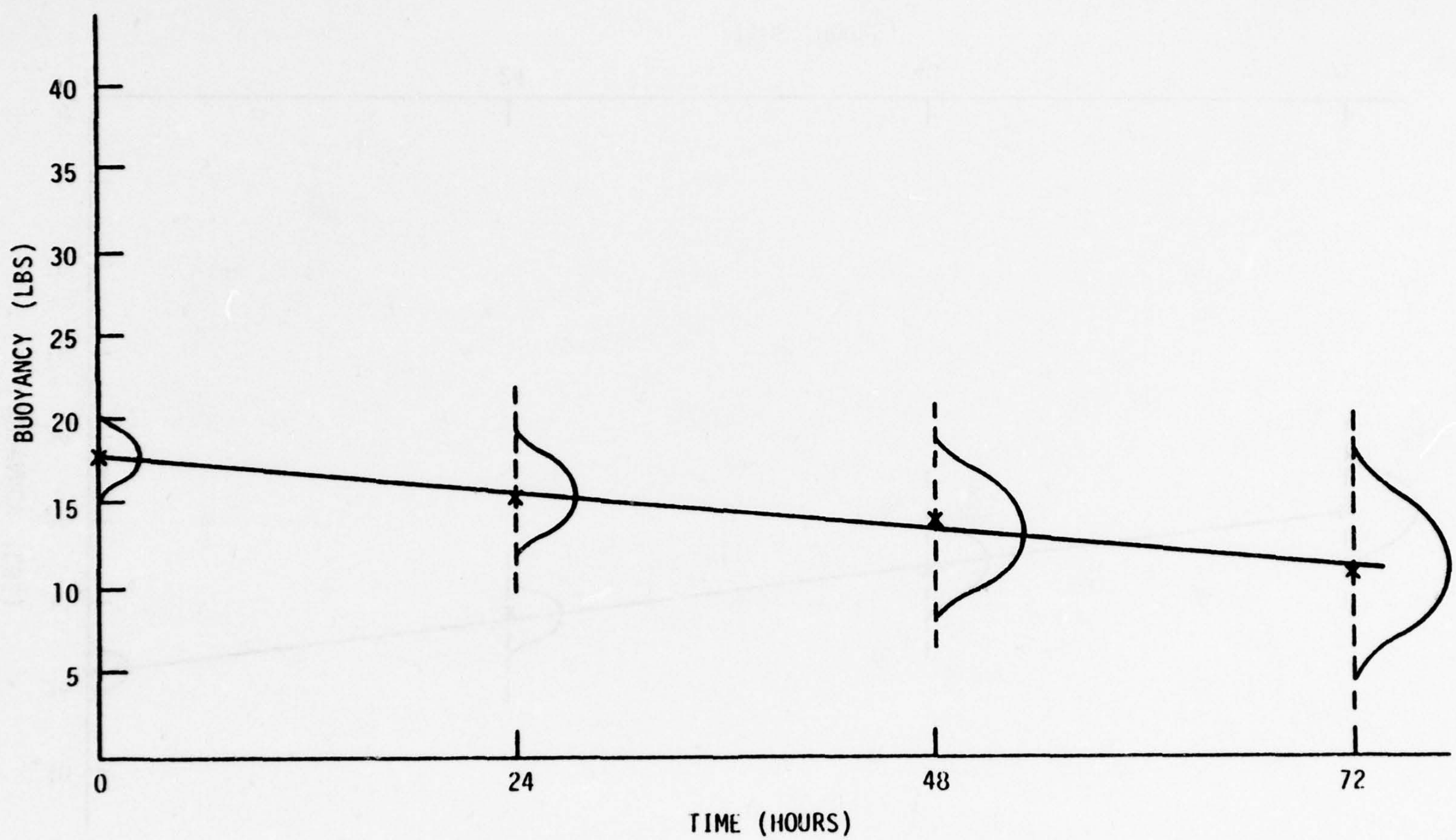


FIGURE V(B)-7. EFFECTS OF PERMEABILITY ON COMMERCIAL TYPE INFLATABLE PFD

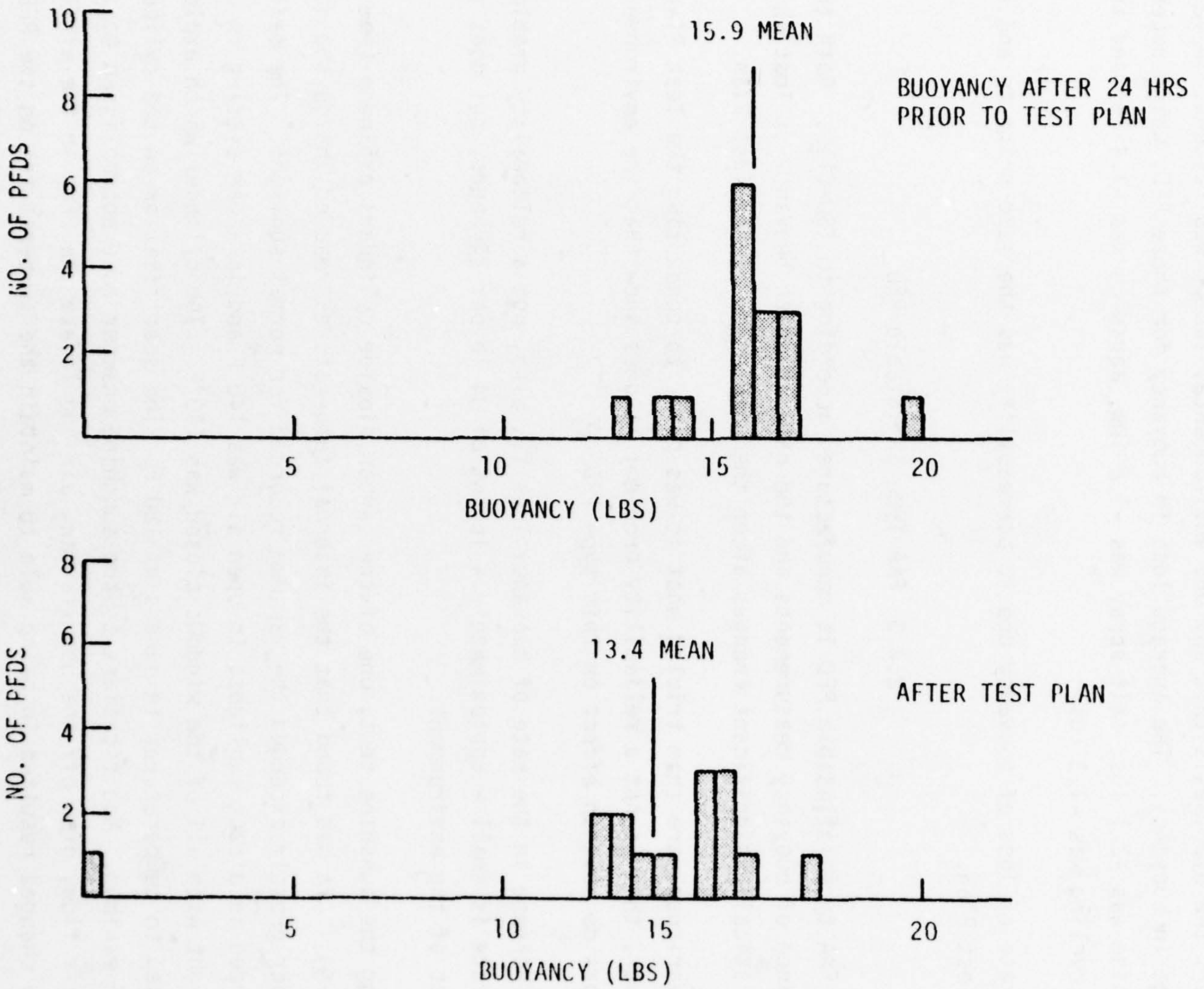


FIGURE V(B)-8. BUOYANCY HISTOGRAM FOR COMMERCIAL INFLATABLE PFDS

Another result is the breakdown of the changes in buoyancy, before and after the Test Plan versus the environmental factor or factors which the PFD experienced. This is shown in Table V(B)-3. It can be seen that 14 of 15 which experienced at least one factor, lost buoyancy. No statistically significant trend was found to support the hypothesis that any one environmental factor was responsible for the change in buoyancy. The average loss in buoyancy for those PFDs which experienced sunshine was -2.1 lbs, salt spray was -1.8 lbs, abrasion was -1.4 lbs and temperature cycling was -1.3 lbs.

The rate of loss of buoyancy due to permeability was the same prior to and after the Test Plan.

2.4.3 FAA Type Inflatable PFD

This FAA type inflatable PFD is manufactured according to TSO-C13C. Both the variance of buoyancy measurements and the rate at which buoyancy is lost showed statistically significant changes after the completion of the Test Plan.

The variance more than tripled what it was prior to conducting the Test Plan; however, this is not a reliability problem; it does show that the environmental factors do have an effect on this type PFD.

The increase in the rate of buoyancy loss is, also, not a reliability problem since the rate is small - approximately 4 lb out of 34 lb per 24 hours, but does show the effect of the environment.

During the sunshine test, one of the carbon dioxide cylinders exploded (see Figure V(B)-9). It was found that the internal temperatures reached inside the sunshine chamber grossly exceeded the maximum recorded for normal sunlight. The maximums recorded in direct sunlight, in open air was 140°F and in a car sitting in direct sunlight with all of the windows closed was 140°F. The cylinder which exploded was exposed to temperatures in excess of 180°F. The specification on the cylinder is 160°F maximum. Modifications to the sunshine chamber were accomplished to increase the air flow, draw off the hot stagnant air and locate the PFDs in the airflow. These changes resulted in being able to maintain the temperatures on the PFDs and components to the range of 140°F to 150°F. Therefore, the failure of this CO_2 cylinder is considered to be a result of the high temperature which is abnormal to the recreational boating environment and thus not a failure mode indicative of the

TABLE V(B)-3. CHANGES IN BUOYANCY VERSUS ENVIRONMENTAL FACTOR EXPERIENCED FOR COMMERCIAL PFDS

CHANGE IN BUOYANCY (LBS)	ENVIRONMENTAL FACTOR EXPERIENCED			
	TEMPERATURE CYCLE	SUNLIGHT	SALT SPRAY	ABRASION
-4.1		X	X	
-3.9	X	X		X
-2.3			X	X
-2.2	X	X	X	X
-2.0		X	X	X
-1.9		X		
-1.3	X			
-1.3	X	X		
-1.2			X	
-1.1	X		X	
-1.0		X		X
-0.7			X	X
-0.4	X			X
-0.4*	X	X	X	
+1.0†	0	0	0	0
+1.5				X

* Did not inflate after testing; this reading was taken after replacement of inflator.

† Stored in a benign environment.

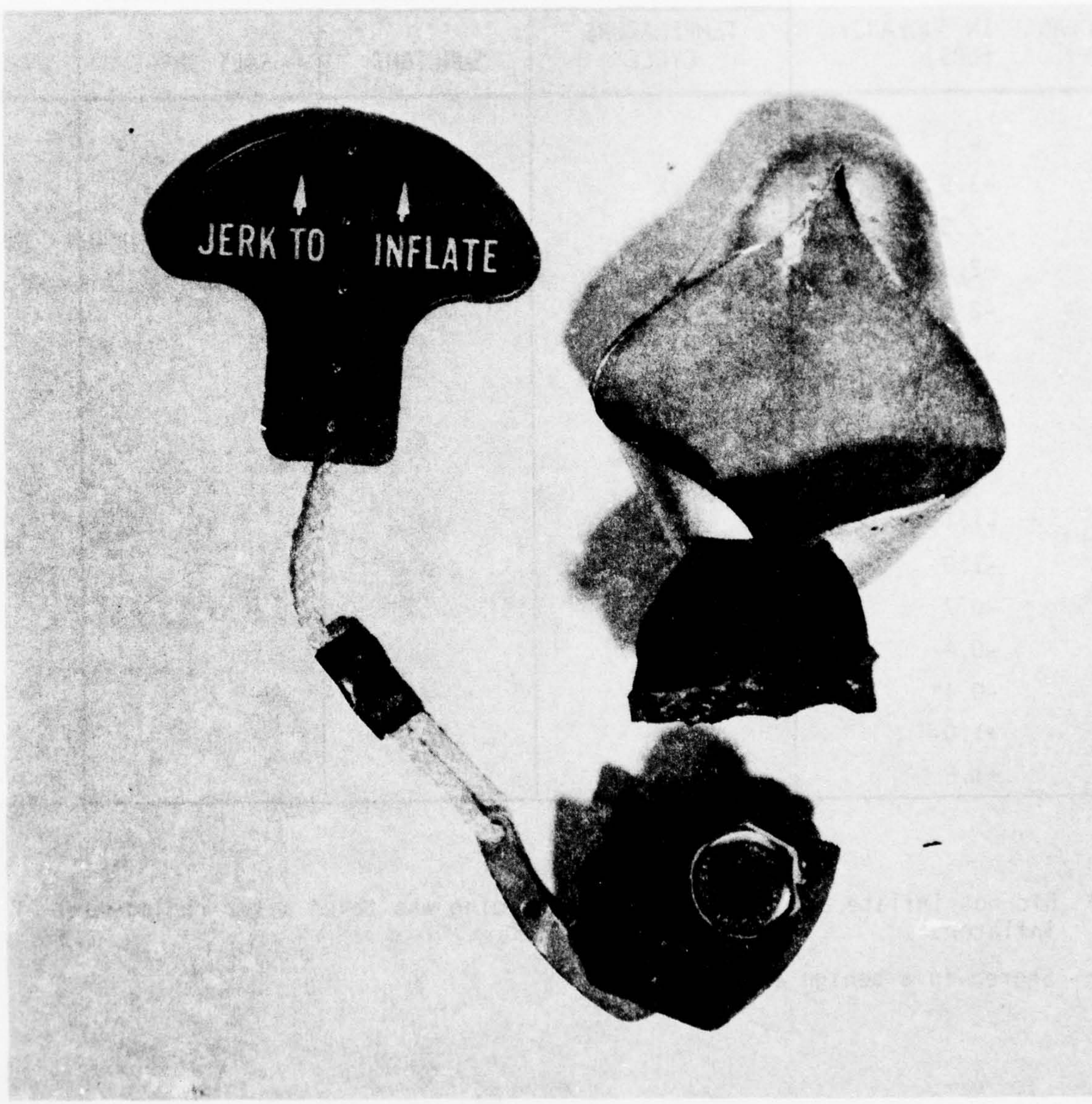


FIGURE V(B)-9. RUPTURED CO_2 CYLINDER SUBJECTED TO ABNORMAL TEMPERATURES

recreational boating environment. It is important in accelerated testing to review the failure modes and mechanisms to make sure that those induced by accelerated testing are indicative of those experienced in the normal environment.

Another failure noted was the failure of one of the chambers to inflate. A failure analysis determined that the cause was a carbon dioxide cylinder which no longer contained the charge. Even though this condition may have been caused by the aforementioned sunshine test, no evidence of overpressure on the cylinder was noted and therefore the failure is concluded to be possible in the recreational boating environment. (This was the only cylinder failure out of 193 cylinders tested).

The mean buoyancy 24 hours after inflation after being subjected to the Test Plan was 31.0 lb as compared to a mean of 32.8 lb buoyancy 24 hours after inflation, prior to the Test Plan. The 31.0 lb average does not include the PFD which had one defective carbon dioxide cylinder. With that one included, the mean drops to 30.0 lb buoyancy. Figure V(B)-10 shows the frequency diagram of the buoyancies before and after the Test Plan.

Another result is the breakdown of the changes in buoyancy, before and after the Test Plan versus the environmental factor or factors which the PFD experienced. This is shown in Table V(B)-4. It is noted that 13 of 14 show a loss in buoyancy; however, the one which was kept in a benign environment exhibited a loss of 0.5 lb. Therefore, only losses of magnitudes significantly exceeding 0.5 lb should be considered as possibly being the effect of the environmental factors. The stratification of the environmental factors with respect to the rank of buoyancy loss suggests that there is not any one environmental factor responsible for the changes in buoyancy.

The average loss of buoyancy for those PFDs which experienced salt spray was -2.3 lb, abrasion -2.2 lb, sunshine -2.1 lb and temperature cycling -1.2 lb.

All PFDs that were exposed to environmental/usage stressors were exposed in the configuration that would normally be worn by a consumer involved in a recreational boating activity. Some PFDs are contained in pouches, holders, or other protective means when they are shipped or stored. These protective means if not necessarily present when the PFD is worn should be disregarded during the testing.

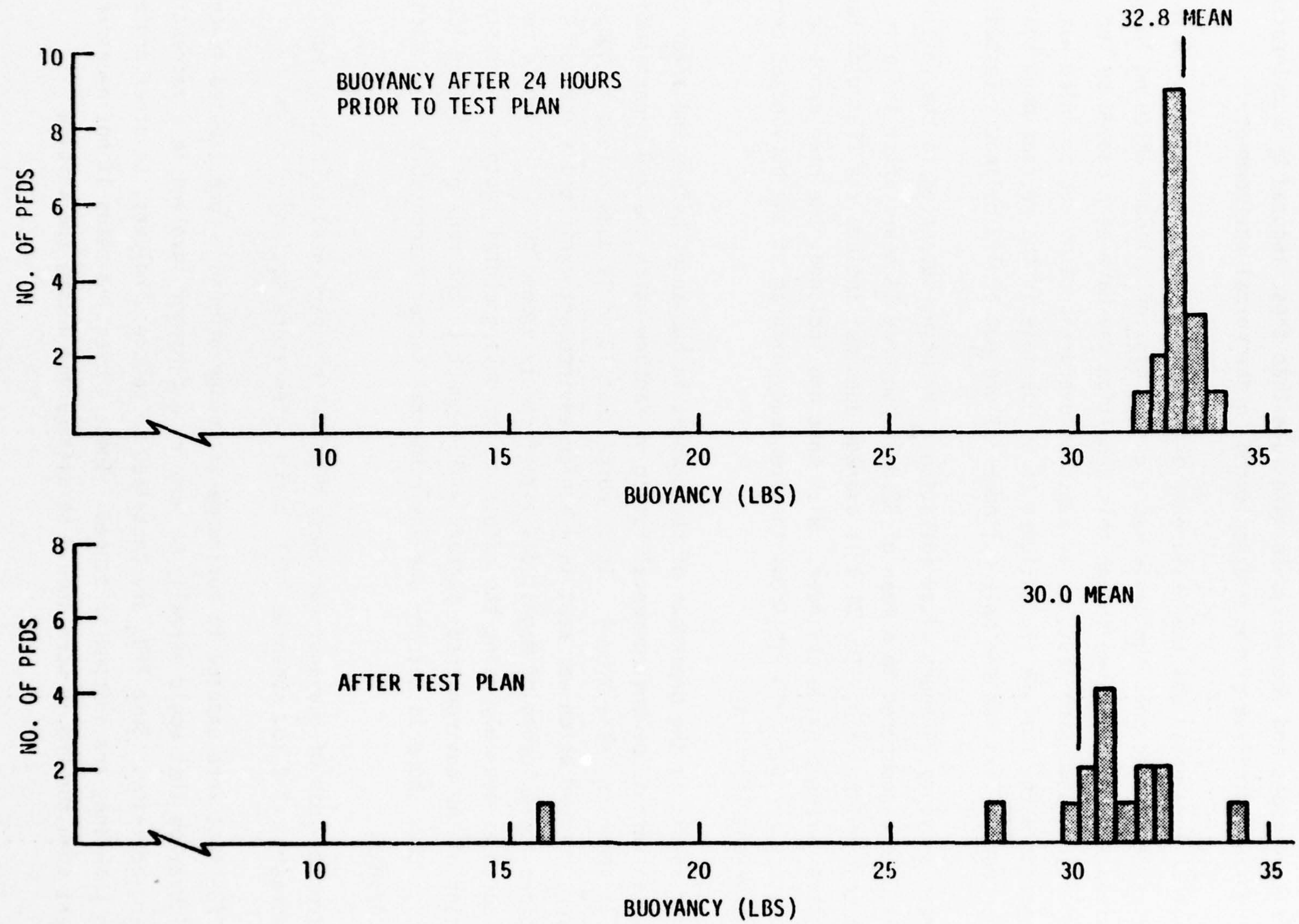


FIGURE V(B)-10. BUOYANCY HISTOGRAM FOR FAA TYPE INFLATABLE PFD

TABLE V(B)-4. CHANGES IN BUOYANCY VERSUS ENVIRONMENTAL FACTOR EXPERIENCED FOR FAA TYPE PFDS

CHANGE IN BUOYANCY (LBS)	ENVIRONMENTAL FACTOR EXPERIENCED			
	TEMPERATURE CYCLE	SUNLIGHT	SALT SPRAY	ABRASION
-5.3			X	X
-3.1	X	X		
-2.5		X	X	
-2.2		X	X	X
-2.1	X	X		X
-1.9			X	
-1.7		X		X
-1.5	X			
-1.4	X		X	X
-1.2		X		
-0.6	X			X
-0.6	X		X	
-0.5*	0	0	0	0
+0.8	X			

* Stored in benign environment.

2.4.4 Navy Type Inflatable PFD

This type of PFD exhibited some interesting results. Because of the unavailability of an adequate supply of carbon dioxide cylinders, only nine of the sixteen samples could be subjected to the Reliability Test Plan. Therefore, the ones tested were subjected to the environmental factors or combinations thereof which were thought to be the most harsh. In spite of this, this group of PFDs resulted in a mean after testing of 31.4 lbs buoyancy as compared to a mean of 31.1 lbs buoyancy prior to the test (see Figure V(B)-11).

A fabric defect was detected in one of these PFDs which caused its buoyancy to be significantly different from the remainder. It exhibited a buoyancy of 25.2 lbs 24 hours after inflation. This fabric defect, while in this case not being catastropic, nor significantly effecting the reliability, was not noticeable until being exposed to the environmental factors. Given a greater occurrence of or greater magnitude, this type of defect could result in a catastropic loss of buoyancy.

Another result is the changes in buoyancy versus the environmental factors experienced. This is shown in Table V(B)-5. It is interesting to note that 7 out of 9 PFDs gained buoyancy after being subjected to the Test Plan. The average change for those PFDs subjected to sunshine was -1.1 lbs, salt spray -0.3 lbs, temperature cycling +0.5 lbs and abrasion +1.1 lbs.

2.4.5 Storage in Air vs. Storage in Water, Between Buoyancy Measurements

The difference in the rate at which buoyancy was lost by storing the PFDs underwater between inflation and the first buoyancy measurement and the second buoyancy measurement was not statistically significant ($t = 0.65$; $p > 0.25$). It is therefore concluded that it makes no difference in the buoyancy measurements to let the PFD dry in air versus water between 24 hour buoyancy measurements.

The testing is simplified then since the PFDs are now allowed to dry in air instead of being submerged in water between when the PFD is inflated and its 24 hour buoyancy measurement.

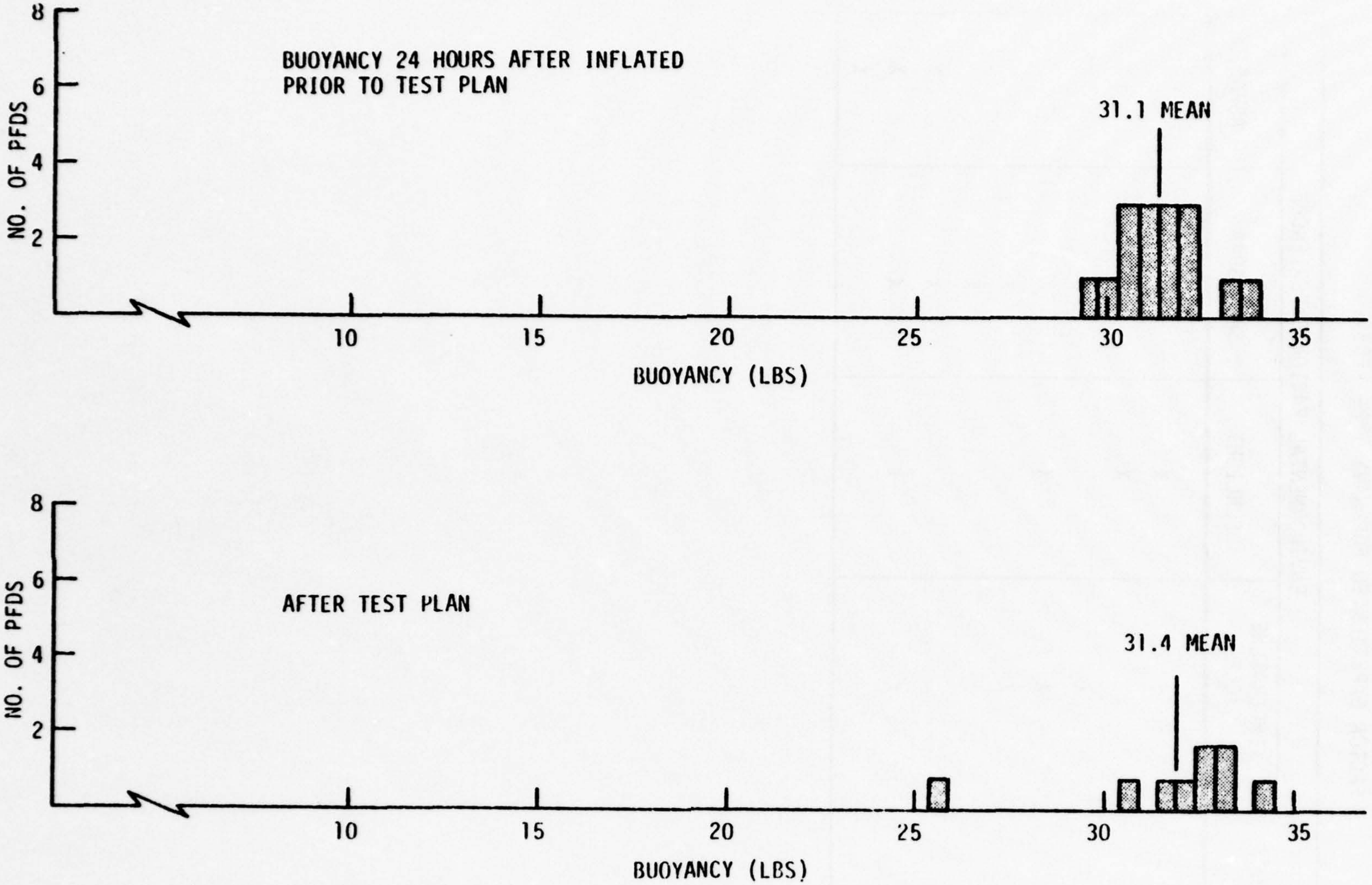


FIGURE V(B)-11. NAVY TYPE INFLATABLE PFDS

TABLE V(B)-5. CHANGES IN BUOYANCY VERSUS ENVIRONMENTAL FACTOR EXPERIENCED FOR NAVY TYPE PFDS

CHANGE IN BUOYANCY (LBS)	ENVIRONMENTAL FACTOR EXPERIENCED			
	TEMPERATURE CYCLE	SUNLIGHT	SALT SPRAY	ABRASION
-5.5		X	X	
-0.4		X	X	X
+0.1	X		X	X
+0.1	X	X	X	
+0.2	X		X	
+0.8			X	
+1.1			X	X
+1.4	X	X	X	X
+3.2				X

3.0 DEVELOPMENT OF RELIABILITY PROCEDURES AND MODEL

The Reliability Test Program showed that the current inflatable technology is capable of producing inflatable PFDs which will withstand the rigors of the environmental stresses present in the recreational boating environment. It also showed that reliability testing can cause latent design or manufacturing problems to become evident. The review of the current standards for inflatables showed that these standards incorporate many essential elements necessary for production of quality inflatable PFDs. A common theme in these standards is that they are design and construction oriented. Some go as far as to specify all materials, fabrication methods and physical construction.

A feature which is not common is a reliability specification. All standards have specifications pertaining to Quality Control and some even specify sampling plans but none perform a complete reliability test to assure the integrity of the PFD for its useful life.

The advantages of a performance oriented standard with reliability tests instead of construction specifications are: first, it fosters innovation and creativity since manufacturers are not tied down to specific construction requirements; second, the merits of each PFD style is based not only on the design but also on the manufacturing and quality control systems of each manufacturer; and third, it binds the manufacturer responsible for his product not only on the day it was manufactured but throughout its useful life.

The proposed reliability specification for inflatable and hybrid PFDs (which is defined in the next section) is a result of evaluating the existing specifications, results of the Reliability Test Plan, and results of the Reliability Analysis accomplished on inherently buoyant PFDs. It may be modified to provide for longer test times, but this will not greatly effect the reliability estimates for the inflatable portions since the failures noted in the Reliability Test Plan, which was run at greatly accelerated times, did not reveal a wearout trend or time period.

The aging procedure developed for use with recreational boating PFDs has made use of relevant MIL-STDs and ASTM Standards where found appropriate. These standards have been used in the manner and purpose intended, that is, as a general guide for developing the more specific aging procedures for recreational boating PFDs.

ASTM procedures are construction standards and the use of construction standards by themselves does not take into account the interactions and synergistic effects. The MIL-STDs are not directly applicable in most instances since they do not represent the recreational boating environment. The intent of these standards and basic procedures have been used with parameters modified to represent conditions found in recreational boating.

3.1 Accelerated Aging Test Sequence

The Accelerated Aging Test Sequence is shown in Figure V(B)-12. The following is an explanation of the elements of this test sequence.

3.1.1 Inspect Literature and PFD

This is a preliminary review to ascertain the readiness of the PFD. Each PFD when in its as received condition should be ready for use with no action required by the consumer to assure its readiness. Any PFD which requires some action on the part of the consumer would be rejected. Some examples of this are inflatable PFDs which do not contain the source of inflation, which require some assembly, or are shipped in a condition which precludes inadvertent operation by also precluding or decreasing the probability of intentional operation. See Figure V(B)-13 for an example of the type of literature which would be cause for rejection.

3.1.2 Unpack PFD

Each PFD in the sample to be tested would be unpacked to the extent that it would normally be worn by a consumer involved in a recreational boating activity. The purpose of this function is to assure that the PFD will be tested in the configuration most likely to be experienced in recreational boating. Some PFDs are contained in pouches, holders, or other protective means when they are shipped or stored. These protective means if not necessarily present when the PFD is worn should be disregarded during the testing. Figures V(B)-14 and V(B)-15 depict protective apparatus which are present during wear and not necessarily present during wear, respectively.

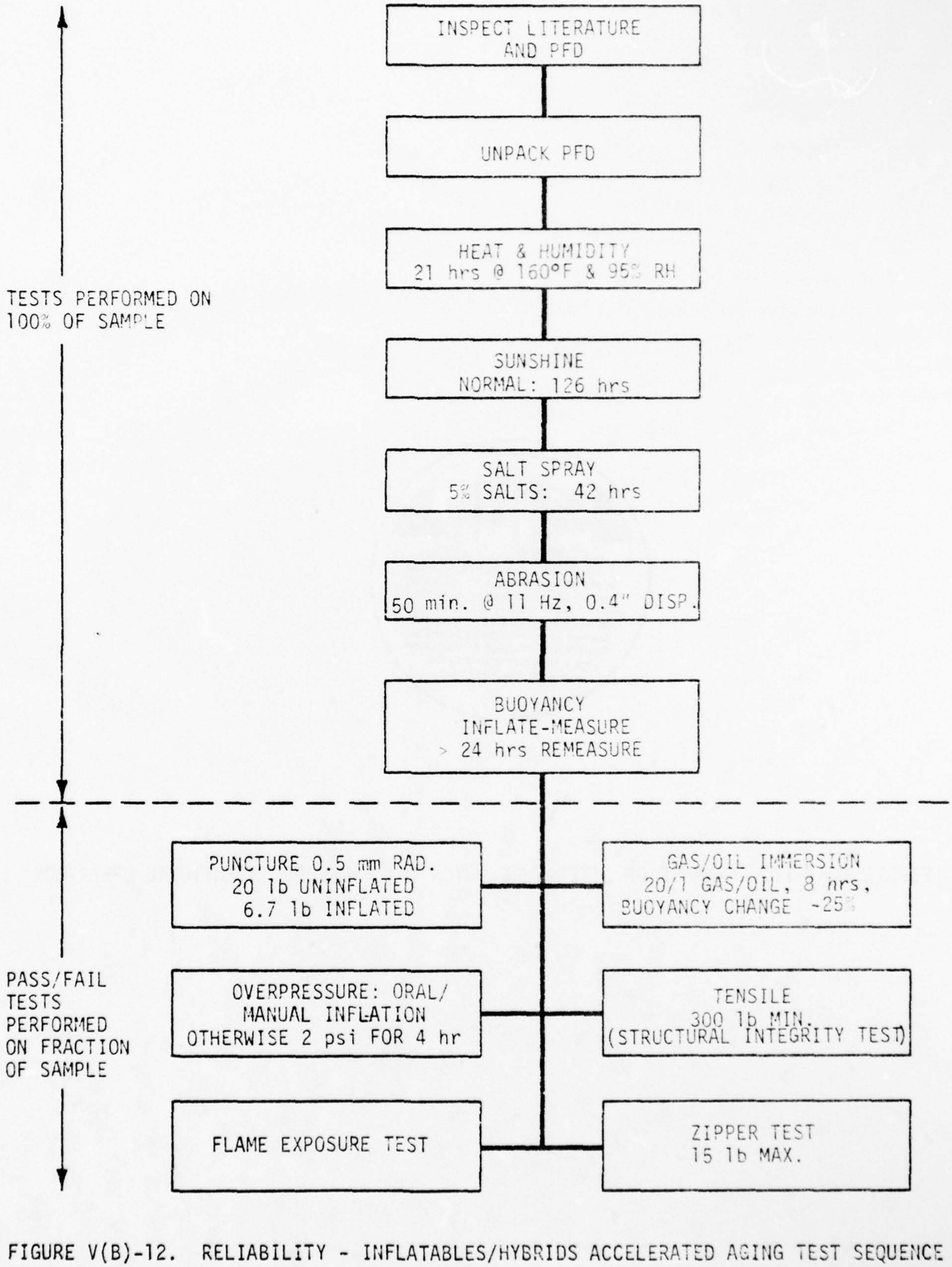


FIGURE V(B)-12. RELIABILITY - INFLATABLES/HYBRIDS ACCELERATED AGING TEST SEQUENCE

FIGURE V(B)-13. EXAMPLE OF LITERATURE WHICH MAY PRECLUDE INTENTIONAL OPERATION

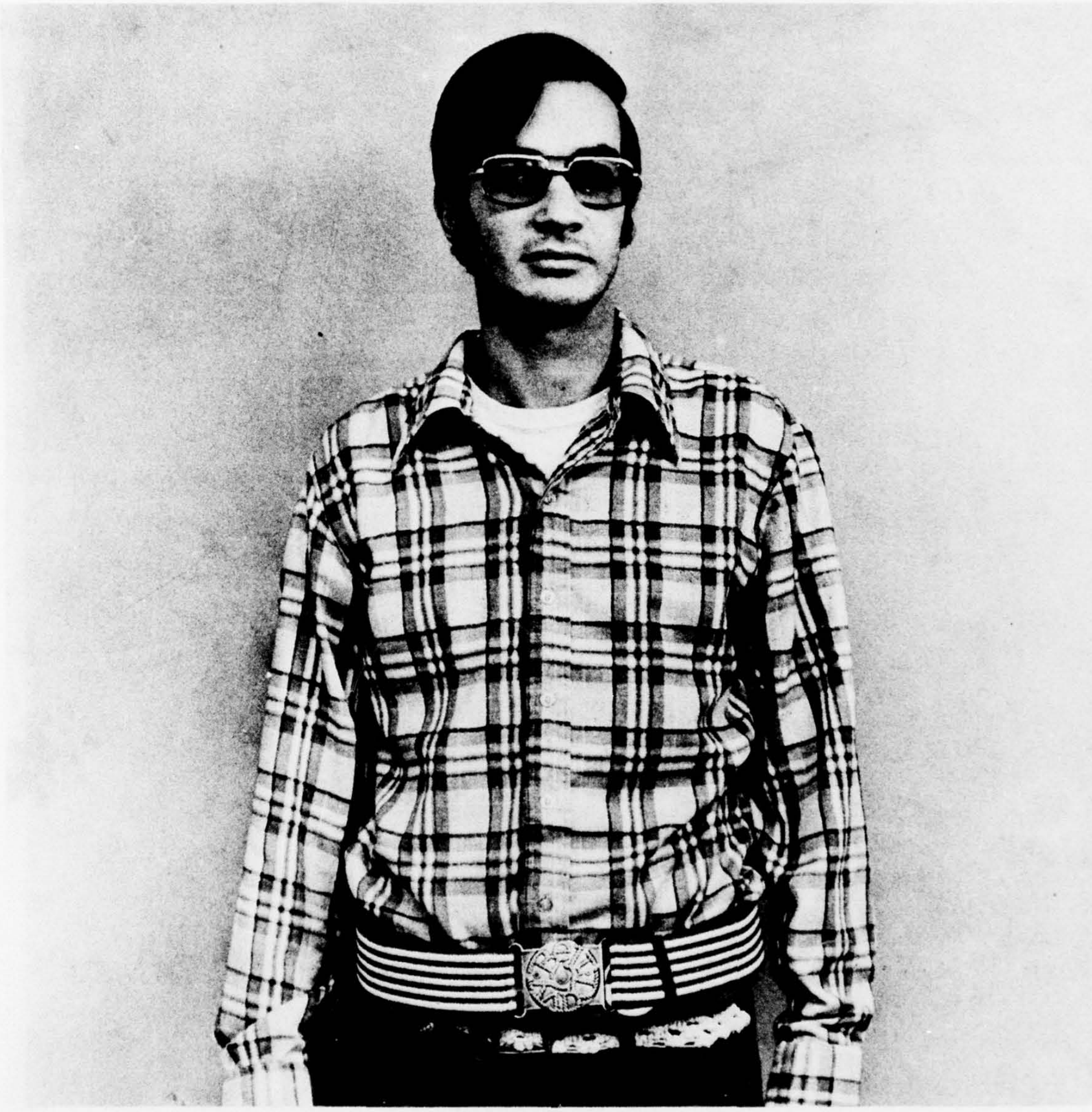


FIGURE V(B)-14. PROTECTIVE COVER WHICH IS PRESENT DURING WEAR, COMMERCIAL TYPE INFLATABLE

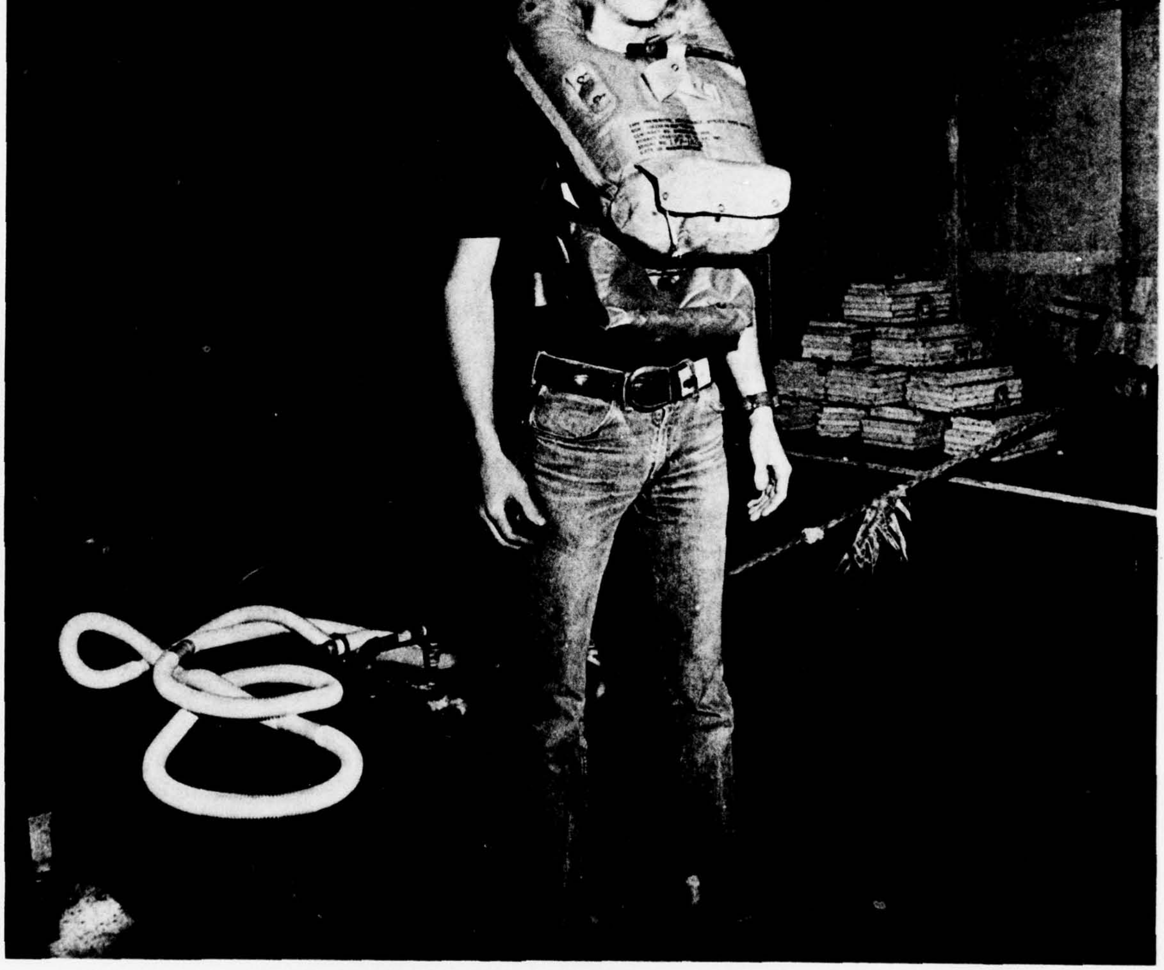


FIGURE V(B)-15. PROTECTIVE COVER WHICH IS NOT NECESSARILY PRESENT DURING WEAR

3.1.3 Heat and Humidity

This test is 21 hours in duration with the temperature at 160°F and 95% RH. The purpose of this test is to evaluate the properties of materials used in a PFD as they are influenced by the absorption and diffusion of moisture and moisture vapor. This is an accelerated environmental test which continuously exposes the PFDs to high relative humidity at an elevated temperature. These conditions impose a vapor pressure on the material of the PFD, which constitutes the force behind the moisture migration and penetration. If the materials are hygroscopic, they are sensitive to moisture and could deteriorate rapidly under humid conditions. Absorption of moisture could result in swelling which may cause loss of physical strength and changes in other important mechanical properties. This test was found to be a significant factor in testing inherently buoyant PFDs.

3.1.4 Sunshine

In order to preclude inducing failure modes which are atypical of the recreational boating environment, the specifications for this test are normal sunlight, 1.17 Langleys per minute for 126 hours (total 8845 Langleys).

3.1.5 Salt Spray

The specification for this test is 5% salts for 42 hours per MIL-STD-810C, Method 509.1

3.1.6 Abrasion

The specification for this test is 50 minutes at 11 Hz and 0.4 in. displacement.

3.1.7 Buoyancy

The PFDs are inflated by using the automatic mode, if present; if no automatic mode is present then the manual mode is used. The inflation time is measured and should be less than eight seconds. The buoyancy is then measured. If the PFD has more than one chamber, this procedure is repeated. The PFD while still inflated is allowed to dry in air for 24 hours at which time the buoyancy is remeasured. The items recorded are the inflation time per chamber, whether the inflator was auto-

matic or manual, the buoyancy for the first chamber, the cumulative buoyancy for two or more chambers, the buoyancy after 24 hours for the whole PFD.

NOTE: This concludes the testing which is performed on 100% of the PFDs in the sample. The sample is now divided evenly for use in the remaining Pass/Fail Tests.

3.1.8 Puncture Resistance

The purpose of this test is to assure a minimum standard of puncture resistance. In so doing, it eliminates those PFDs which have a high probability of becoming punctured. The test consists of a force gauge which has a point which is 0.5 mm radius (standard medium pen point). In the uninflated condition, a force of 20 lb is applied at random to the fabric of the chamber. The PFD should be inflated using the automatic or manual mode. The PFD is considered to have passed if there is no evidence of leakage from the area subjected to the 20 lb force.

The force gauge is now applied to the previously inflated PFD. The PFD is considered to have passed if the PFD did not puncture after the applied force reaches 6.7 lbs or the PFD punctures at a force greater than 6.7 lbs.

3.1.9 Overpressure

The purpose of this test is to assure that the PFD will not explode and thus result in a catastropic failure when subjected to conceivable overpressures. If the PFD has both an oral and a manual inflator, then this test consists of orally inflating the PFD to its maximum; then while the PFD is fully inflated, actuate the manual inflator. The resulting pressure inside the PFD is typically 8-10 psi.

If the PFD only has a manual inflator, it should be inflated to 2 psi which is typically double the normal inflation pressure. In either case, the PFD is considered to pass it it does not lose more than 20% of the inflation pressure in four hours.

3.1.10 Flame Exposure

The test plan includes a two-second flame exposure test such as that outlined in UL 1123.

Coast Guard research to date has not indicated a need for a test more severe than the two-second flame exposure test in order to insure boaters' safety.[1]

Additional work is required to evaluate other fire related hazards to PFDs (such as operator induced stressors) which might become significant if the LSI system is implemented, due to the availability of new types of PFDs and changes in utilization patterns, such as increased wear. For example, inflatable and hybrid PFDs could suffer loss of buoyancy from cigarette burns.

One alternative considered was a flammability test. The purpose of such a test is to assure that the PFD will not support combustion. This can be determined from the following: the time it takes for a PFD to become self-extinguishing after application of a flame; that the PFD does not support violent burning; that exposure of a PFD to a flame does not result in an explosive type fire; or that spreading of surface burning on larger parts is deterred.

The external flame would be applied by the use of a match on an edge of the PFD in a vertical axis for 12 seconds, then removed. The time of burning of visible flame on the PFD would be recorded. Any violent burning or explosive type fire would be recorded. The PFD would be considered acceptable if the time of visible flame is less than 30 seconds and no violent burning or explosive type fire is noted.

3.1.11 Gas/Oil Immersion

The purpose of this test is to preclude the approval of PFDs which deteriorate when subjected to a gasoline/oil mixture. A 20 to 1, gas to oil ratio mixture is prepared and the subject PFDs are immersed in this mixture for 8 hours. After being allowed to dry for 48 hours, the PFDs are buoyancy tested as per 3.1.7. The difference in buoyancy measured during this test as compared to the prior buoyancy before this test should not exceed 20%.

---

[1] Personal communication from CDR Charles Niederman, USCG.

3.1.12 Tensile

The purpose of this test is to assure the structural integrity of the PFD, after being subjected to the 100% tests indicative of the recreational boating environment. The test is accomplished on the fixture shown in Figure V(B)-16. The PFD shall be capable of withstanding 300 lb without failure.

3.1.13 Zipper Test

The purpose of this test is to assure the operability of any zippers. A PFD shall be considered as satisfactorily completing this test if the force it takes to zip up the zipper is 15 lbs or less after it has been subjected to the 100% tests of this sequence.

3.2 Reliability Prediction Model

3.2.1 Introduction

The Accelerated Aging Test sequence defined the tests to which the inherently buoyant, inflatable and hybrid PFDs are subjected. It also defined the records to be maintained from these tests. The following details how the records result in a Reliability Index for the PFD.

3.2.2 Model

The reliability of the PFD is determined from the results of the Accelerated Aging Test Sequence, data obtained during this research on buoyancy requirements, reliability estimates for various inflation systems, and PFD characteristics. This information is placed in the Reliability Index formula, Figure V(B)-17 and the index calculated. The elements of the index are determined as follows:

3.2.2.1 % Population Supported - An important reference document is the Probability Plot of Buoyancy Requirements, Figure V(B)-18. This data represents the cumulative probability distribution of buoyancy requirements which was generated as part of the Effectiveness section of this report. It relates the buoyancy to the percent of the adult male population which require this specific amount of buoyancy or less. After the Accelerated Test Sequence has been performed on a sample of PFDs, the mean buoyancy for the sample is found from the buoyancy results

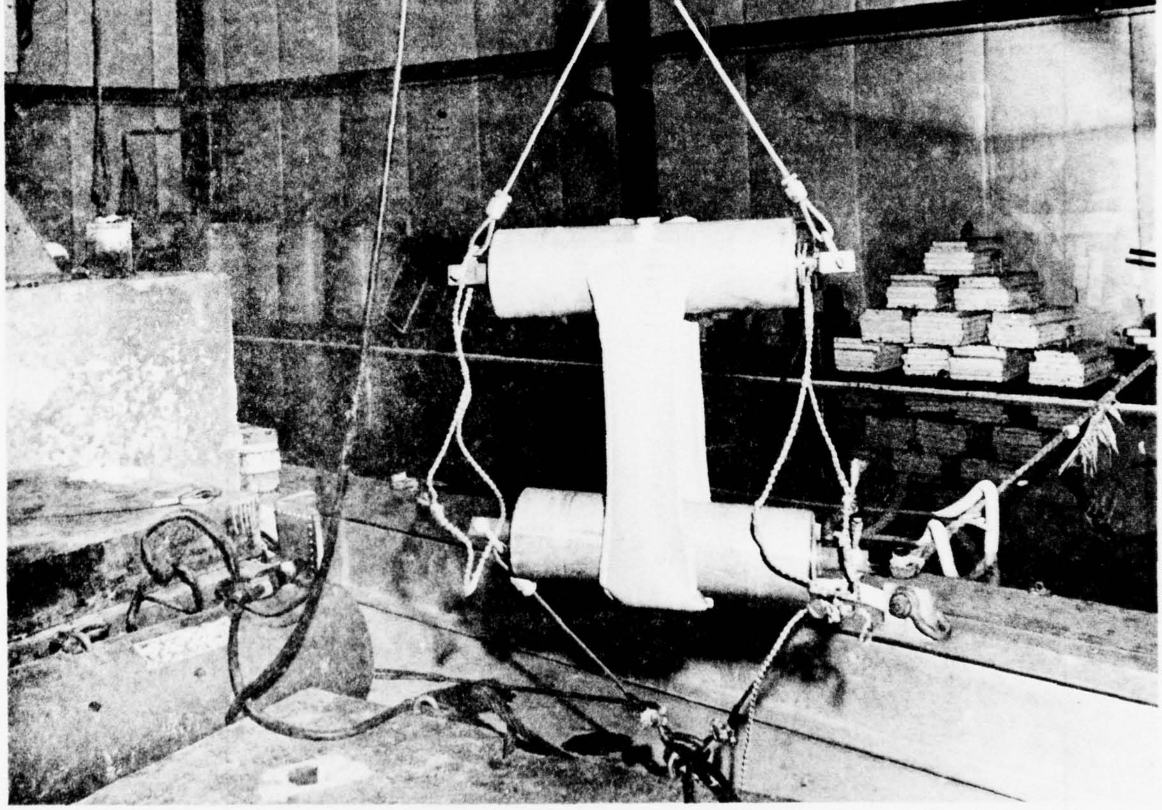


FIGURE V(B)-16. TENSILE TEST APPARATUS, SHOWN WITH COMMERCIAL TYPE PFD BEING TESTED

RELIABILITY INDEX

$$= P_r\text{ (Inflatable)} + P_r\text{ (Inherently Buoyant)} - [P_r\text{ (Inflatable)} \times P_r\text{ (Inherently Buoyant)}]$$

where:

$$P_r\text{ (Inflatable)} = P_r\text{ (Good Chamber)} \times P_r\text{ (Inflate)} \times \%\text{ Population Supported}$$

$$P_r\text{ (Inherently Buoyant)} = \%\text{ Population Supported}$$

and

$$P_r\text{ (Inflate)} = P_r\text{ (Manual)} + P_r\text{(Oral)} + P_r\text{ (Automatic)}$$
$$- [P_r\text{ (Manual)} \times P_r\text{ (Oral)}] - [P_r\text{ (Manual)} \times P_r\text{ (Automatic)}]$$
$$- [P_r\text{ (Oral)} \times P_r\text{ (Automatic)}] + [P_r\text{ (Manual)} \times P_r\text{(Oral)} \times P_r\text{ (Automatic)}]$$

And for two redundant chambers, Reliability Index is the same except for:

$$P_r\text{ (Inflatable)} = 2P_r\text{ (Good Chamber)} \times P_r\text{ (Inflate)} \times \%\text{ Population Supported}$$
$$- [P_r\text{ (Good Chamber)} \times P_r\text{ (Inflate)} \times \%\text{ Population Supported}]^2$$

FIGURE V(B)-17. RELIABILITY INDEX FORMULA

from Step 3.1.7. This mean is then plotted on the vertical scale of Figure V(B)-18 and followed to the buoyancy requirement line and where it intersects this line, the percent of Population Supported is read from the scale at the top.

If the PFD has both inherently buoyant and inflatable sections, i.e., a hybrid, the buoyancy is counted as a contribution from each individually. That is, the cumulative buoyancy is not used.

3.2.2.2 Probability of a Good Chamber = P_r (Good Chamber) - This is defined as the number of chambers which had at least some buoyancy, divided by the total chambers tested for this type PFD.

3.2.2.3 Probability That a Chamber Inflates = P_r (Inflate) - This is the probability that the event, that the chamber inflates by any means, occurs. The possible means of inflation are manual, automatic, and oral. They are further defined as follows:

3.2.2.3.1 Probability of Manual Inflation = P_r (Manual). This is the probability that an inflator and its inflation means which is designed to be actuated by some deliberate action by the wearer of the PFD other than using an oral valve, actually operates. It is derived from the lesser of the two: the number of inflators which operated properly during the test divided by the number of such inflators tested, or an established probability of inflation for this type of an inflation sytem.

3.2.2.3.2 Probability of Automatic Inflation = P_r (Automatic). This is the probability that an inflator, which is designed to actuate without any deliberate action by the wearer of the PFD, actually operates. It is derived from the lesser of the two: the number of inflators which operated properly divided by the number of such inflation systems tested, or an established probability of inflation for this type of an inflation system.

3.2.2.3.3 Probability of Oral Inflation ≡ P_r (Oral). This is the probability that an inflator, which is designed to actuate by oral means, actually operates. It is the lesser of the two: the number of inflators which operated properly divided by the number of such inflators tested; or an established probability of inflation for this type of an inflation system.

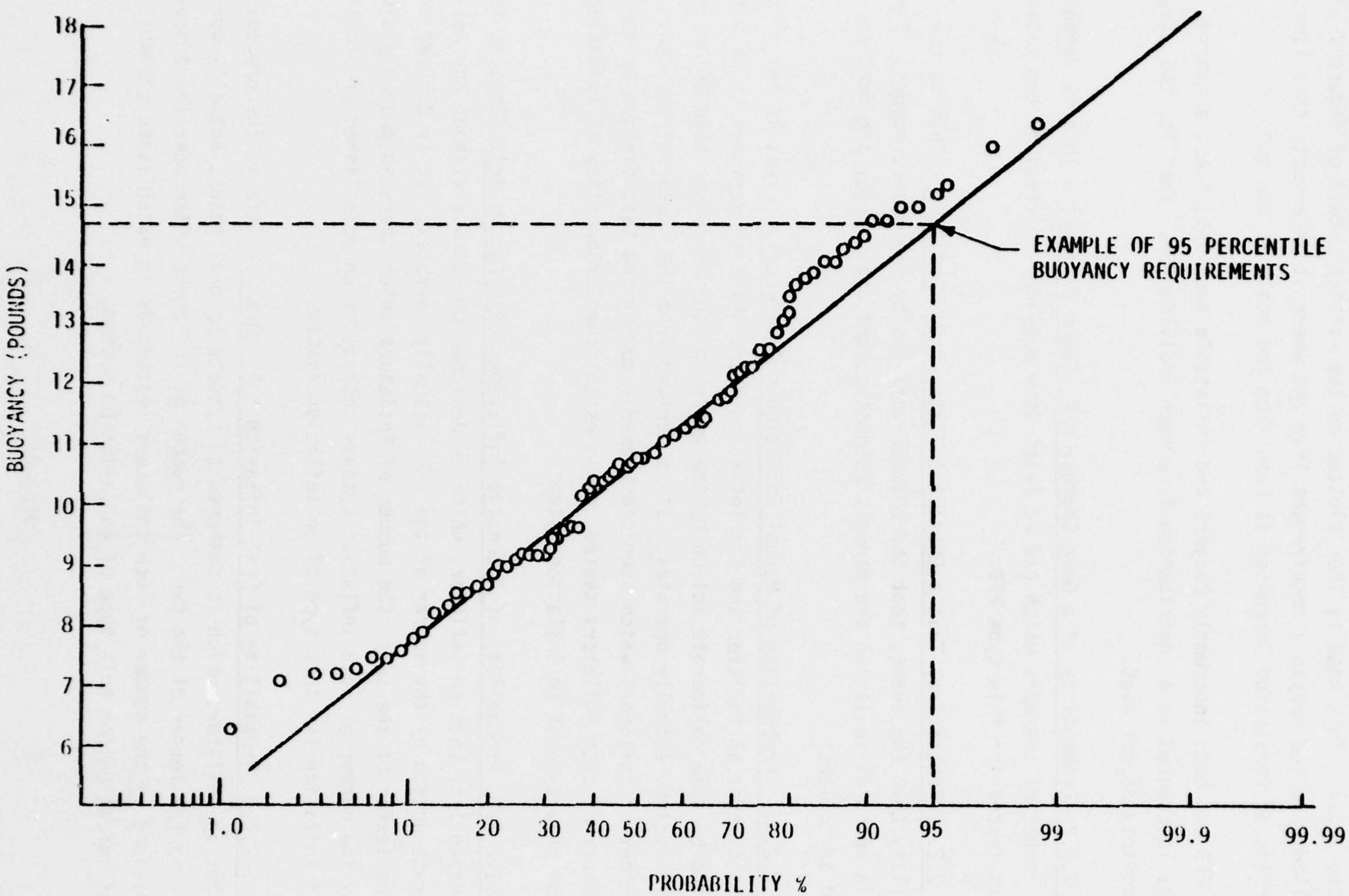


FIGURE V(B)-18. CUMULATIVE PROBABILITY DENSITY FUNCTION FOR BUOYANCY REQUIREMENT

4.0 RESULTS OF ACCELERATED AGING TESTING

Three types of inflatable PFDs were subjected to the Accelerated Aging Test Sequence as outlined in Section 3.0. The results of the testing are presented here along with the Reliability Index for each type.

4.1 PFDs Tested

Three different types of inflatable PFDs were tested. They were the Navy type, the FAA type, and the commercial type. In addition, two chambers on one FAA type tested contained a new prototype automatic inflator which uses a 16 gram carbon dioxide cylinder as its inflation means.

4.2 Buoyancy Results

The buoyancy measurements are shown in Table V(B)-6. The average inflation times were: Navy - 6.8 seconds, FAA - 3.7 seconds, and commercial - 7.8 seconds.

Using the Cumulative Probability Graph for Buoyancy Requirements, Figure V(B)-18 we estimate the percent of population supported to be as shown in Table V(B)-7.

4.3 Pass/Fail Tests

The results of the puncture tests are shown in Table V(B)-8. All PFDs passed this test.

The overpressure tests resulted in internal pressures of 8.75 psi in the Navy type and 9.5 lbs in the FAA type without failure. The commercial type which does not have an oral inflation mechanism was subjected to 2 psi without failure. All units passed the gas/oil immersion and tensile test. There are no zippers on these units.

The FAA type did not pass the alternate flammability test and continued to burn until it was fully consumed (see Figure V(B)-19). The Navy type did not support any combustion and the commercial type stopped burning within 10 seconds after the flame was removed (see Figure V(B)-20).

Based upon the results of these tests, the FAA type would fail a flammability test.

TABLE V(B)-6. BUOYANCY MEASUREMENTS AFTER ACCELERATED AGING TEST SEQUENCE

NAVY		FAA				COMMERCIAL	
		1st CHAMBER		BOTH CHAMBERS			
INITIAL	AFTER 24 HOURS	INITIAL	AFTER 24 HOURS	INITIAL	AFTER 24 HOURS	INITIAL	AFTER 24 HOURS
36.9	32.9	19.1	--	37.9	34.2	18.6	16.6
36.5	31.3	18.9	--	37.7	34.2	18.0	15.2
36.3	33.5	18.8	--	37.4	32.8	17.6	16.3
35.8	33.1	19.1	--	37.1	32.9	17.4	14.4
35.6	33.2	18.7	--	37.1	32.5	17.4	16.0
35.5	33.4	18.7	--	36.7	29.8	17.2	15.2
35.4	32.7	18.8	--	36.5	30.1	17.1	15.3
35.2	32.7	19.1	--	36.5	32.7	13.8	11.4
35.1	32.7	18.7	--	36.5	32.9	13.6	10.4
35.0	30.3	18.8	--	36.3	29.5		
34.7	29.9	19.1	--	36.2	32.8		
34.6	30.0	19.1	--	36.0	32.3		
34.5	30.2	18.2	--	36.0	31.4		
34.5	31.5	16.6	--	34.8	31.7		
34.2	31.7						
33.0	27.3						
33.0	30.6						

MEAN

35.05	31.59	18.69	--	36.62	32.13	16.74	14.53

TABLE V(B)-7. PERCENTAGE OF POPULATION SUPPORTED VS. INFLATABLE PFD TYPE AFTER ACCELERATED AGING

PFD TYPE	MEAN BUOYANCY/CHAMBER	% POPULATION SUPPORTED
Navy	31.59	100%
FAA	32.13/2 = 16.07	98.7%
Commercial	14.53	94%

TABLE V(B)-8. PUNCTURE TEST RESULTS

PFD TYPE	FORCE TO PUNCTURE	
	UNINFLATED	INFLATED
Navy	20 lbs - No Puncture	12 lbs
FAA	20 lbs - No Puncture	9 lbs
Commercial	20 lbs - No Puncture	7.9 lbs

KAPOK AK-1

FAA TYPE
INFLATABLE

FIGURE V(B)-19. RESULTS OF FLAMMABILITY TEST

NAVY TYPE
INFLATABLE

COMMERCIAL TYPE
INFLATABLE

FIGURE (V)B-20. RESULTS OF FLAMMABILITY TEST

4.4 Inflation System Reliability

During the test the only failures noted in the inflation systems were the prototype automatic inflators. Two automatic inflators were tested. One inflated during the heat and humidity test and the other did not inflate after being submerged in water during the buoyancy test. Therefore this type of automatic inflators would receive a probability of operation, P(Automatic) = 0. (Previous testing of this type of automatic inflators resulted in P(Automatic) = 0.4).

The Navy manual inflators exhibited no failures and the established reliability estimate for this type inflator showed no failures out of 44. At 50% confidence this yields a lower limit on the reliability of this type of inflator of 98.5%. The established limit will be used since this is the lesser.

The FAA Manual inflators exhibited no failures and the established reliability estimate for this type of inflation system was 1 failure out of 95. At 50% confidence, this yields a lower limit on the reliability of this type of inflator of 98.2%. The established limit will be used since it is the lesser.

The commercial type manual inflator exhibited no failures and the established reliability estimate for this type of inflation system was 1 failure out of 50. At 50% confidence, this yields a lower limit on reliability of this type of inflator of 96.8%. The established limit will be used since it is the lesser.

No oral inflators failed and the established reliability estimate for the oral inflators is no failures out of 139. At 50% confidence, this yields a lower limit on reliability of oral inflators of 99.5%. The established limit will be used for both the Navy and FAA types since they have oral inflators.

4.5 Chamber Reliability

During all of the testing no chambers were found to be defective. All of them retained buoyancy for the 24 hours after inflation. One was tested up to 120 hours after inflation and it was found to have 53% of its initial buoyancy. It is interesting to note that even the inflatables which were punctured in the puncture test still maintained some buoyancy after 24 hours.

The established reliability is no failures out of 189. At 50% confidence, this yields a lower reliability limit of 99.65%. The established limit will be used since it is the lesser.

4.6 Calculation Of Reliability Index

The calculations for the Reliability Index for the three types of inflatable PFDs subjected to the Accelerated Aging Test Sequence is as shown in Table V(B)-9. This data is at a 50% confidence level.

4.7 Sensitivity Analysis

At the 50% confidence level, the most reliable of the inflatables is the FAA type because of its totally redundant chambers, manual inflators, and oral inflators. The Navy type has a higher probability of inflating per chamber and has a higher percentage of population supported per chamber, but this does not overcome the advantages of the totally redundant FAA type.

The commercial type does not have an oral inflator nor does it have any type of redundancy. It also supports a lesser percentage of the population due to its lower buoyancy than the other types.

If we increase our confidence level, some interesting results take place. Table V(B)-10 shows the results of the different confidence levels.

Because of the larger sample tested of the FAA type, the lower reliability limit for the probability of manual inflation becomes bigger than the same limit for the Navy type even though no failures were noted in the Navy type. Therefore, sample size has an effect on the results. The use of components which have established failure rates would take advantage of the sample size factor because an established rate would include many more samples than would normally be tested during the Accelerated Aging Test Sequence.

The percent change in reliability, based upon the change in confidence level from 50% to 95%, was for the Navy type -2.5%, for the commercial type -13.1% and the FAA type -0.1%. The very small change in the FAA type is attributable to the effect of the total system redundancy.

TABLE V(B)-9. RELIABILITY INDEX

PFD TYPE	P_r (MANUAL)	P_r (AUTOMATIC)	P_r (ORAL)	P_r (INFLATE)	P_r (GOOD CHAMBER)	% POPULATION SUPPORTED	P_r (INFLATABLE)	P_r (INHERENTLY BUOYANT)	RELIABILITY INDEX
Navy	0.985	0	0.995	0.999925	0.9965	1.00	0.9964	0	0.9964
FAA Single Chamber	0.982	0	0.995	0.99991	0.9965	0.987	0.9835	0	0.9835
FAA 2 Redundant Chambers	0.982	0	0.995	0.99991	0.9965	0.987	0.9997*	0	0.9997*
Commercial	0.968	0	0	0.968	0.9965	0.94	0.9067	0	0.9067

* Use Redundant Chamber Calculations.

TABLE V(B)-10. SENSITIVITY ANALYSIS

CONFIDENCE LEVEL	PFD TYPE	P_r (MANUAL)	P_r (AUTO-MATIC)	P_r (ORAL)	P_r (INFLATE)	P_r (GOOD) CHAMBER)	% POPULATION SUPPORTED	P_r (INFLAT-ABLE)	P_r (INHERENTLY BUOYANT)	RELIABILITY INDEX
50%	Navy	0.985	0	0.995	0.999925	0.9965	1.0	0.9964	0.38	0.9978
	FAA*	0.982	0	0.995	0.99991	0.9965	0.987	0.9997	0.38	0.9998
	Commercial	0.968	0	0	0.968	0.9965	0.94	0.9067	0.38	0.9422
80%	Navy	0.965	0	0.988	0.99958	0.991	1.0	0.9906	0.38	0.9942
	FAA*	0.967	0	0.988	0.9996	0.991	0.987	0.9995	0.38	0.9997
	Commercial	0.94	0	0	0.94	0.991	0.94	0.8756	0.38	0.9229
90%	Navy	0.95	0	0.983	0.99915	0.988	1.0	0.9872	0.38	0.9921
	FAA*	9.958	0	0.983	0.99929	0.988	0.987	0.9993	0.38	0.9996
	Commercial	0.923	0	0	0.923	0.988	0.94	0.8572	0.38	0.9115
95%	Navy	0.9	0	0.965	0.9965	0.975	1.0	0.9716	0.38	0.9824
	FAA*	0.93	0	0.965	0.9976	0.975	0.987	0.9984	0.38	0.9990
	Commercial	0.86	0	0	0.86	0.975	0.94	0.7882	0.38	0.8687

* Redundant Chambers

Also analyzed in the sensitivity data in Table V(B)-10 is the effect of adding a fixed amount of inherently buoyant material to the inflatable PFD. In this example, it is assumed that after the Accelerated Aging Test Sequence, the mean buoyancy of the inherently buoyant material is 10 lbs. From Figure V(B)-18, it is determined that 10 lbs of buoyancy results in supporting 38% of the population. This value is added into Table V(B)-10 and the Reliability Index calculated using the formula in Figure V(B)-17. At the 95% confidence level, the extra inherently buoyant material of 10 lbs would yield an increase in reliability for the Navy type of +0.0108, for the FAA type of +0.0006 and for the commercial type of +0.0806.

It is also possible to calculate the amount of fixed inherently buoyant buoyancy which is needed to upgrade an inflatable to a specific Reliability Index. For example, to increase the Reliability Index for the commercial inflatable PFD from 0.7882 to 0.99 we solve the equation

$$\text{Reliability Index} = P_r(\text{Inflatable}) + P_r(\text{Inherently Buoyant}) - P_r(\text{Inflatable}) \times P_r(\text{Inherently Buoyant})$$

$$0.99 = 0.7882 + P_r(\text{Inherently Buoyant}) - 0.7882 \times P_r(\text{Inherently Buoyant})$$

$$P_r(\text{Inherently Buoyant}) = 0.9528$$

From Figure V(B)-18, this corresponds to a buoyancy of 14.8 lbs.

Thus, the Reliability Index formula and Figure V(B)-18 can be used as a design aid to develop a hybrid PFD which could meet any specified Reliability Index. They also could be used for trade-off studies between the inflatable portion and the inherently buoyant portion to satisfy a specified index.

5.0 FAILURE MODE AND EFFECT ANALYSIS

The normal purpose of the Failure Mode and Effect Analysis (FMEA) is to evaluate a specific design by enumerating the various failure modes of each component, estimating the effect on the total system and estimating its seriousness. In addition, a recommendation is made to minimize the possibility of the failure. A minor change is made in the FMEA in this report and that is that the FMEA is based upon a generalized design and not any specific design of an inflatable PFD. The reason for this is to point out the general potential failure modes which are applicable to inflatable PFDs and provide recommendations for minimizing them. The recommendations could be used by a manufacturer voluntarily or could become a requirement in an official specification. Each specific design should also be studied in this manner so that action can be taken on problems peculiar to the design.

The results of this general FMEA provide, in some cases, the justification for a specific test in the accelerated aging test sequence. They also point out which failure modes a specific test requirement is meant to detect.

5.1 Discussion of FMEA

The FMEA, Table V(B)-11, describes, by component, the possible failures and the sources of failure - the failure mechanism, that is the cause of the failure. Next an estimate is made as to the probability of occurrence, the likelihood of damage to surrounding components and the seriousness of the failure to the system. In this case the seriousness of the system means the ability of the PFD to operate as intended in order to provide buoyancy for the wearer. These estimates given here are meant to be subjective rather than definitive of actual probabilities. (Actual probabilities based on tests performed during this research are designated in Section 4.0.)

The effect on the system is stated and a corrective action is recommended which would reduce or eliminate the failure.

TABLE V(B)-11. FAILURE MODE AND EFFECT ANALYSIS

SYSTEM: INFLATABLE PFDS

PERSON MAKING ANALYSIS: GLEASON
DATE: 9/9/77

COMPONENT	POSSIBLE FAILURE	CAUSE OF FAILURE (FAILURE MECHANISM)	P	D	S	EFFECT OF FAILURE ON SYSTEM	CORRECTIVE ACTION TO REDUCE OR ELIMINATE
Bladder	Leakage	1. Puncture	3	1	3	1. Loss of adequate buoyancy	1.1 Puncture resistant material; puncture test 1.2 Protective cover
		2. Seam failure	1	1	5	2. Catastrophic loss of buoyancy	2.1 Proof test during manufacture
Oral Inflator	Cannot inflate	1. Valve not working	1	1	2	1. Cannot orally inflate or top up	1.0 Inspection during manufacturing
		2. Torn from bladder	2	5	5	2. Won't maintain buoyancy	2.1 Tensile test 2.2 Protected prior to need
Inflator	Won't inflate	1. Cylinder not punctured	1	1	5	1. No buoyancy	1.0 Oral inflator as backup
		2. Broken inflator	2	1	5	2. No buoyancy	2.1 Strength test of inflator 2.2 Thermal cycling to detect defects
		3. Lanyard broken	1	1	2	3. Have to operate by fingers	3.0 Pull test on lanyard
		4. Corroded	2	3	5	4. From difficult to operate to breaking inflation assembly off of PFD	4.0 Salt spray test
Inflator	Leakage	1. Seal broken	1	5	5	1. From loss of adequate buoyancy to catastrophic loss	1.1 Tensile test 1.2 Oral inflator as backup

P = Probability of Occurrence   D = Likelihood of Damage to Surrounding Components   S = Seriousness of Failure to the System

1 = Very Low or None (< 1 in 10)   2 = Low or Minor (2 in 10)   3 = Medium or Significant (50-50)   4 = High (7 in 10)
5 = Very High or Catastropic (> 9 in 10)

TABLE V(B)-11. FAILURE MODE AND EFFECT ANALYSIS (concluded)

SYSTEM: INFLATABLE PFDS

PERSON MAKING ANALYSIS: GLEASON
DATE: 9/9/77

COMPONENT	POSSIBLE FAILURE	CAUSE OF FAILURE (FAILURE MECHANISM)	P	D	S	EFFECT OF FAILURE ON SYSTEM	CORRECTIVE ACTION TO REDUCE OR ELIMINATE
Inflator (continued)	Leakage (continued)	2. Inflator breaks	2	1	5	2. From loss of adequate buoyancy to catastrophic loss	2.1 Thermal cycling test 2.2 Oral inflator as backup
		3. Gasket Missing	2	1	5	3. From loss of adequate buoyancy to catastropic loss	3.1 Proof test during manufacture
Cylinder	Leakage	1. Hole in cylinder	1	1	5	1. No buoyancy	1.1 Leakage test 1.2 21 day weight test
	Bursts	1. Inadequate structural integrity	1	5	5	1. No buoyancy	1.0 Hydrostatic pressure test
		2. Overcharged	1	5	5	2. No buoyancy	2.0 Spec on filling ratio
	Ruptures	1. Design problem or workmanship	1	5	5	1. No buoyancy, possible projectile	1.0 Lot sample for rupture

P = Probability of Occurrence   D = Likelihood of Damage to Surrounding Components   S = Seriousness of Failure to the System

1 = Very Low or None (< 1 in 10)   2 = Low or Minor (2 in 10)   3 = Medium or Significant (50-50)   4 = High (7 in 10)
5 = Very High or Catastropic (> 9 in 10)

5.1.1 Bladder

The most probable failure of the bladder is leakage which could be caused by puncture or seam failure. The punctures which were created by the puncture test did not result in an immediate complete loss of buoyancy. Rather, these punctures could be overcome by topping up with an oral inflation system. That is why the seriousness of the failure is only meidum. Puncture resistant materials and protective covers will aid in preventing this type of failure.

The actual probability of occurrence of a puncture failure will be related to the hazards of the recreational boating environment. Therefore, an approach to minimizing this type of failure is to establish a minimum puncture standard. The proposed standard is 20 pounds for an uninflated PFD. This is based upon the assumption that a PFD is more likely to become punctured when worn or stored when it is uninflated. The 20 pounds is derived from minimum forces exerted by humans and which requires leverage to accomplish.

The force required to puncture an inflated PFD is 6.7 pounds and is based upon the Austrailian standard. When inflated, it is reasonable to assume that the wearer is in the water, where the chance of puncture is lessened. Also this magnitude of force would cause some of it to be imparted to the PFD as a velocity, thus reducing the puncture force.

Seam failures could result in a catastrophic loss of buoyancy; however, since none were found in the testing it is concluded that the proof or overpressure testing which is currently being accomplished by the manufacturers is sufficient to minimize the possibility of this type failure.

5.1.2 Oral Inflator

The problem of a defective oral inflator would best be checked during manufacturing since the designs evaluated were fairly simple and the most probable causes of failures would be assembly oriented.

To minimize the possibility of the inflator being torn from the PFD, the portion should normally be protected when the PFD is uninflated and the means of attachment should be sufficient to survive a significant potential force.

5.1.3 Inflator

The inflator is characterized by having many potential failure mechanisms, almost all of which could result in a catastrophic failure. The one which is assumed to have the highest probability of occurrence is the possibility of corrosion. The salt spray test will aid in eliminating this failure mode except for extreme environments which may require stainless steel components.

Another corrective action which has much merit is the suggestion of thermal cycling tests since it could help reduce the possibility of two of the enumerated failure mechanisms.

5.1.4 Cylinder

A failure with this portion of the PFD may result in a catastrophic failure to the PFD. The problem of leakage is addressed by the Austrailians and the British by requiring a measurement of the cylinder and, after 21 days, remeasurement of the cylinder. The U. S. military specifications require a water pressure test. While these measures help, they have not eliminated this failure, since one was evidenced during the Reliability Test Plan. The need for redundancy, such as an oral inflator is evident. Because of the danger involved, any cylinder to be considered for approval should be made to rigidly defined specifications as regards hydrostatic pressure testing, filling ratios and rupture. The current U. S. military specifications contain such stipulations.

5.2 Critical Failures

The definition of a critical failure is one which has a high probability of occurrence and a high seriousness of failure to the system.

Critical failures require immediate attention and would be cause for serious consideration for non-approval.

No critical failures were noted in this analysis.

6.0 INFLATION SYSTEMS

During this research, it was possible to observe several inflation systems and inflator mechanisms. The following is a cursory discussion of some of the available types or possible types, their advantages and/or problems.

6.1 Lanyard Operated Manual Carbon Dioxide System

This is the most common inflation system. Inflation is by means of an expendable carbon dioxide cylinder. A typical example is as shown in Figure V(B)-21. Inflation is made by a manual pull on a handle connected to the lanyard which operates a cam which causes the pin to pierce the cylinder. An internal spring forces the pin back out of the cylinder so that it will not impede the flow of carbon dioxide into the chamber. The body of the device is made from various materials such as fibre reinforced polyester or aluminum dye castings. The cadmium plated hardened cold rolled steel was sufficient in our 168 hour salt spray to provide corrosion resistance to the metal parts. Stainless steel is also available.

The cost of this type inflator, depending on quantity, runs from $2.88 down to $1.95 per system including the carbon dioxide cylinder.

Another advantage of this type is that they had threaded metal cylinders for the mating of the carbon dioxide cylinder which helps prevent cross threading and therefore a false indication that the cylinder is fully seated. If it is not fully seated, there is a possibility that the pin will not pierce the cylinder and even if it does the gas could escape into the atmosphere.

A disadvantage to this system is the lack of an indication of no charge in the cylinder. Other problems and recommendations to minimize them are found in the Failure Mode and Effects Analysis.

This type inflation system exhibited an estimated reliability of 90% for the Navy type and 93% for the FAA type at a 95% confidence level.

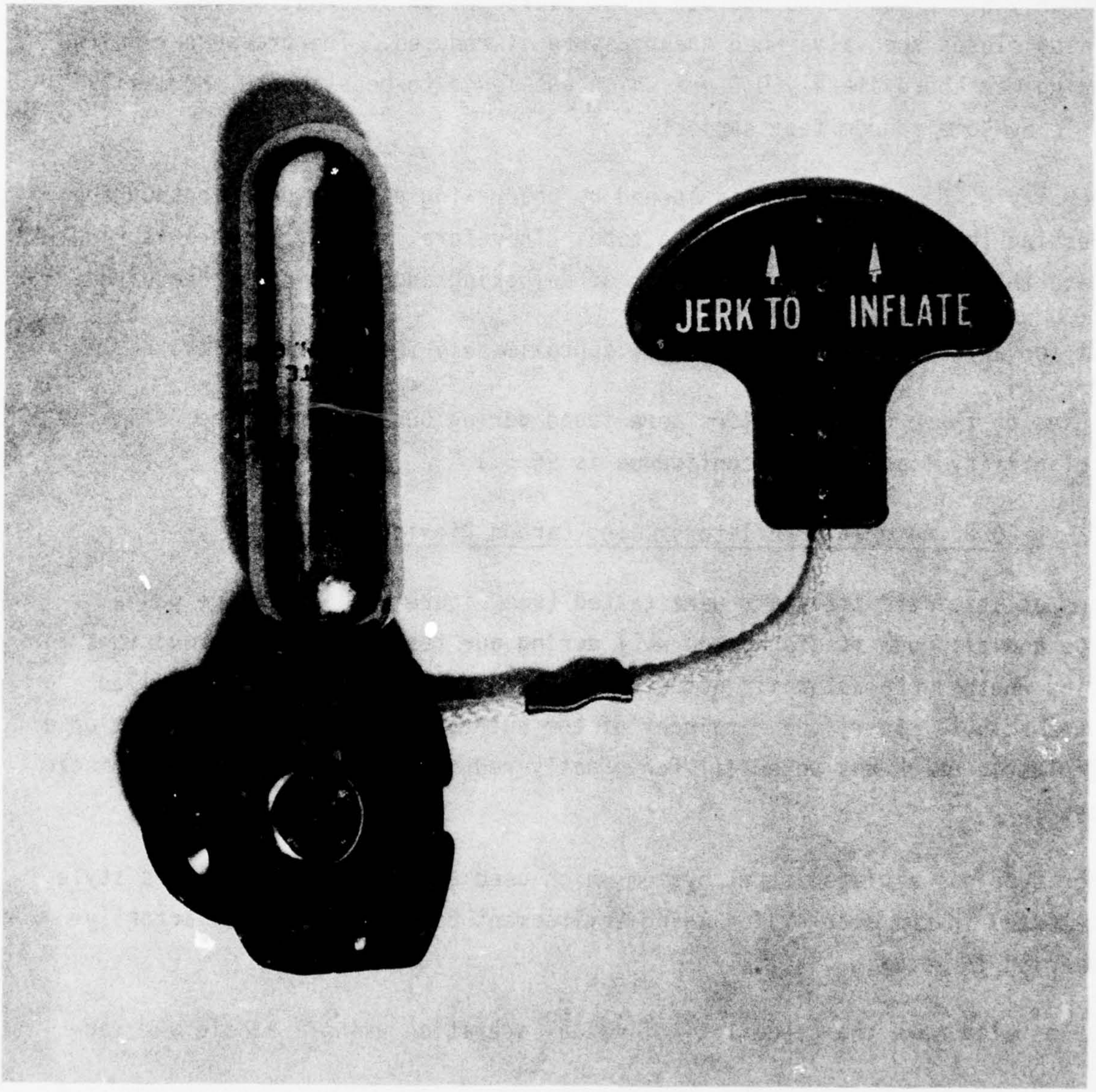


FIGURE V(B)-21. TYPICAL MANUAL INFLATOR

6.2 Oral Inflator

Two styles were prevalent in the oral inflators (see Figure V(B)-22). The FAA type requires only air pressure to operate as it overcomes an internal spring. This spring also closes the valve when the pressure is reduced. The pressure required for opening was approximately 0.6 psi which was found to be standard and easily attainable by some random test subjects.

The other style, the Navy type, is opened by unscrewing a high speed locknut and then pressing the mouth piece into the tube. Therefore, no air pressure is required to operate this inflator but the actions of unlocking and pressing are required.

The cost for an oral inflation system is approximately $0.73 in quantity.

No failures of these oral inflators were found during our testing. The estimated lower reliability limit at 95% confidence is 96.5%.

6.3 Automatic Inflators Using Carbon Dioxide Cylinders

Two types of automatic inflators were tested (see Figure V(B)-23). One was a prototype and although it did not do well during our testing, it had provisions for indicating whether the automatic actuator had been fired. Except for a coiled spring and soluble paper, the remainder of the automatic portion was made out of a type of plastic which has potential for greatly reducing the cost of the automatic inflators.

The other type was a plated steel system which used a soluble tablet. This style was not tested in the accelerated aging environment but did work satisfactorily when immersed in water.

Both styles also have the capability of manual operation using a handle and lanyard.

6.4 Solid State Inflators

The term solid state as referred to in this context is referring to the fact that the propellent is in a stable state and not under great pressures while it is stored prior to actuation. Current applications of this type of inflation system are in commercial aircraft evacuation slides, rafts, and in the automotive passive restraint systems (air bags).

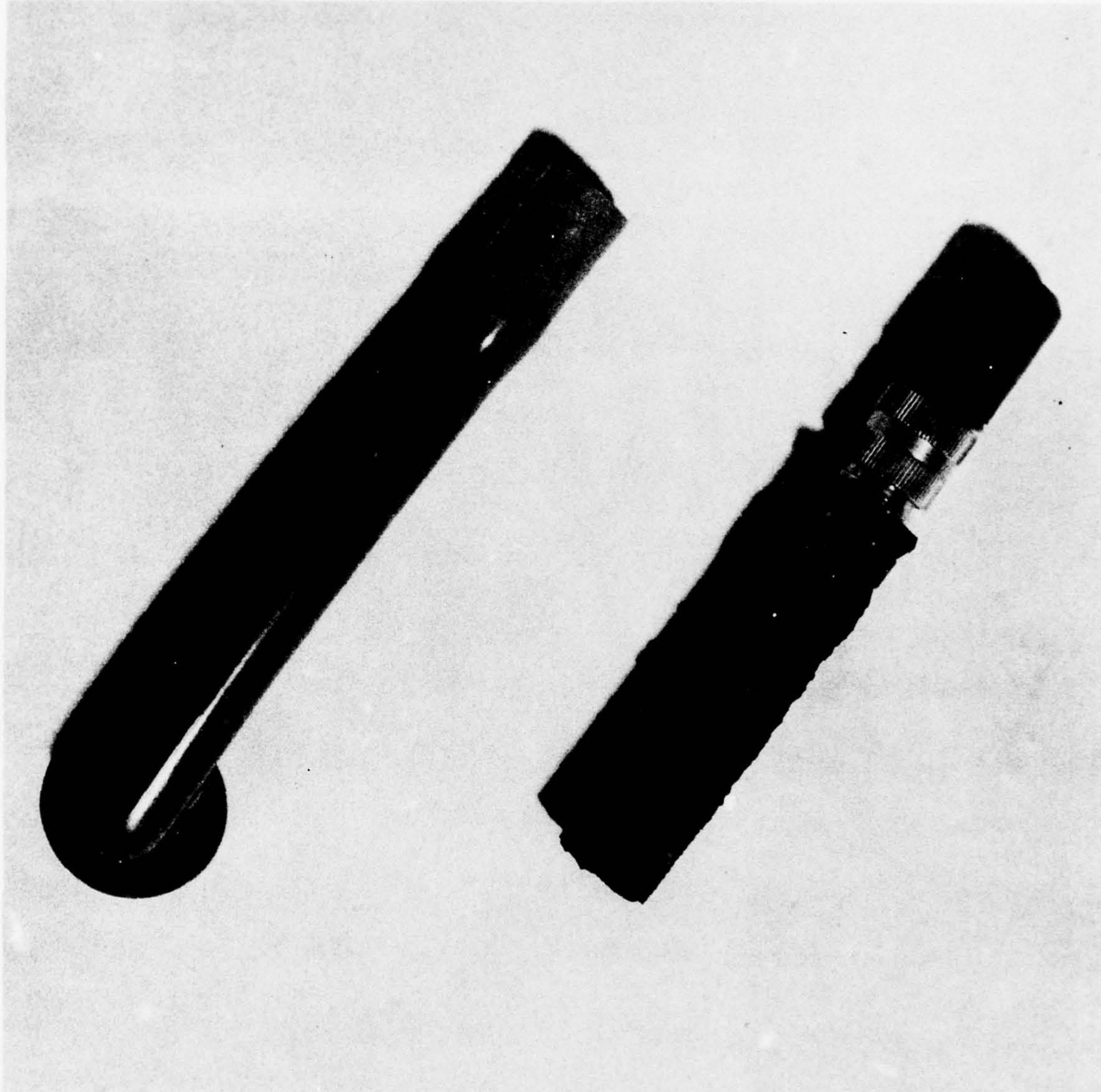


FIGURE V(B)-22. TYPICAL ORAL INFLATORS

FIGURE V(B)-23. AUTOMATIC INFLATORS

A system has not been fully developed for use in a PFD but work is continuing. All manufacturers who were contacted agreed with the feasibility of solid state inflators for PFDs. Some noted problems which would have to be solved, such as the temperature reached during generation of the gas. In air bags using sodium azide this could be 600°F to 800°F. Some experts thought that temperatures in the range of 150°F were feasible using heat exchangers or liquid refrigerent.

The elevated temperatures generated by the means of inflation could result in the PFD becoming a heat source. This heat source could possibly be of benefit in hypothermia protection.

Another advantage of this type of potential inflator is that the expended unit shows a color change so that the readiness of the system could be checked.

The reliability could make this system advantageous also since the type for slides and rafts has an expected reliability of 99.95% at 95% confidence, based on testing by the manufacturer. This type is operated via a lanyard.

The type used in air bags has a predicted reliability of 99.999%. Although the results to date in the National Testing Program for air bags in which they have been installed in approximately 12,000 automobiles has resulted in 351 actuations out of a possible 354. This results in an estimated reliability of 97% at the 95% confidence level.

The air bag systems are triggered by a squib which puts out 1.4 amps for 2 milliseconds. A compatible type triggering mechanism would be needed in the event that this technology is applied to PFDs.

Another potential advantage is the speed of inflation. Typically, air bags inflate in 20-40 milliseconds as opposed to 4-8 seconds for current carbon dioxide systems. This could mean an added life saving potential especially with respect to unconscious victims or sudden drowning victims.

The cost of this type of inflator, designed to work in an inflatable PFD, is estimated to be greater than $10 per system.

SECTION VI.

THE ACCIDENT RECOVERY MODEL

TABLE OF CONTENTS

SECTION VI LIST OF FIGURES

SECTION VI LIST OF TABLES

SECTION VI

THE ACCIDENT RECOVERY MODEL

1.0 SUMMARY

The Accident Recovery Model (ARM) has been developed as an analysis tool, with related techniques and procedures that organizes and summarizes accident data so that the role of personal flotation devices in saving lives can be evaluated and the impacts (in terms of reducing fatalities) of existing and proposed regulatory and educational programs can be assessed. The discussions in this section demonstrate how ARM has fulfilled its dual purpose.

ARM was developed as a versatile and general data analysis model, in response to the complex and interactive nature of the processes by which boating accident victims live and die. The model is empirical, and represents an organized and structured data base. The development of ARM was an iterative process, requiring repeated development of parts of the model, and testing by processing accident data. In order to accomplish the desired versatility and generality of ARM, the model was designed to encompass a large number of variables in the accident data. A detailed sampling and weighting plan was devised for the selection of the accidents to be processed, and the projection of these data to represent the entire data base of the Coast Guard for reported recreational boating accidents. The boating accident reports in the ARM sample were each coded independently by two analysts, and the codings were verified by computer and a third analyst (the verifier). About 10% of the verified codings were reviewed by senior project personnel for accuracy. Thus, the data were sampled, coded, verified, and weighted in order to accurately mirror the recreational boating accidents for an "average" year.

The basic results reported in this section indicate that the ARM data base is representative of the Coast Guard's data. The thorough examination of those results in the text, variable by variable, points out the need for more detailed analysis and statistical techniques in order to examine several variables simultaneously. The ARM data are compared to Coast Guard data for geographical distribution, time of day, month, and other variables in the pages that follow, in order to establish the representativeness of the ARM data. Additional analyses are generated which illustrate the influences of boat parameters, environmental factors, and people's behavior on the probability that an individual survives his or her accident. Several of these

variables display similar tendencies in the data, indicating the need for multiple variable analyses.

The basic results also indicate problem areas in recreational boating. These were identified by the low probabilities of recovery corresponding to victims in parts of ARM. For example, it was found that certain boat types (canoes, kayaks, open manual boats, and "other" boats) are associated with low chances for survival in an accident, while others (powerboats, cabin cruisers, houseboats, and sail boats) are involved in accidents where people are much more likely to live. For "type of power," all types of propulsion were associated with comparable probabilities of recovery except "manual," which had a very low chance of survival associated with it. Such results abound in the presentation of the ARM data.

The detailed analyses revealed significant interrelationships between variables and their effects on a victim's chances for survival. In particular, it was found that PFD wear was highly associated with severe conditions on other variables (water conditions, victim's circumstances, and others). For example, a victim who wore a PFD was much more likely to have been in rough water than a victim who didn't wear a PFD. The victim who didn't wear, was much more likely to have been in calm water. This means that variables such as water conditions can introduce biases in the comparisons (overall) of PFD wearers to non-wearers. A solution to this problem is to include an analysis of variables other than those of direct interest to a particular estimate or evaluation for their possible biasing effects on that estimate or evaluation. Examples of these "multi-state" solutions are included in this section of the report.

It is shown that ARM can be used to measure the relative importance of PFD properties such as self-actuation of inflatables, the ability to turn an unconscious wearer, the quality of being highly wearable, and effectiveness and reliability over time. For example, it is shown that: 1) there is very little evidence of a reliability problem with PFDs in the accident data, and 2) nearly three-fourths of the fatalities, for whom time in the water is known, occur in the first 15 minutes. Thus, it appears that a PFD can save many lives if it is worn, it may not need to function for a long time (especially with the advent of level flotation in the future), and hypothermia protection may not be of great importance in a great number of cases where fatalities occur in such a short time.

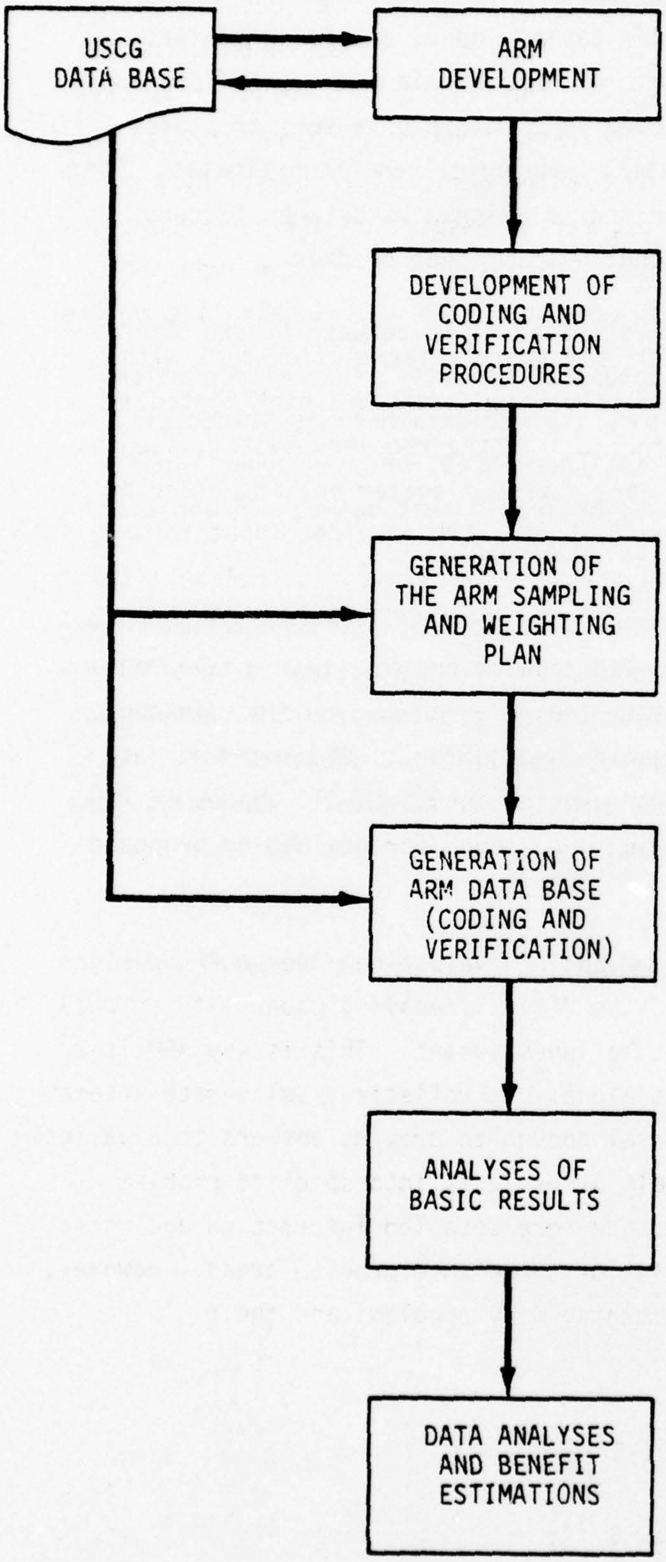
ARM is used to generate quantitative estimates of the benefits of hypothesized and actual changes in recreational boating (changes in PFD wear, changes in PFD properties, i.e., the Life Saving Index, educating boaters to stay with their boats, and the effects of hypothermia and level flotation). The approach of breaking down each problem into multiple factors or states has proven fruitful in terms of generating meaningful benefit estimates. This approach is necessitated by the strong interrelationships between factors which determine whether a boating accident victim lives or dies.

The current annual benefit for PFDs is estimated to be between 50 and 124 lives saved. The upper bound for the potential benefits of level flotation is estimated to be 255 lives saved. Since the ARM data base is historical, and very few level flotation boats are included in it, only an upper bound could be generated for that case. It was estimated that between 26 and 202 boating deaths per year are influenced by hypothermia.

Finally, a statistically significant linear relationship is found between the average Life Saving Index for the PFD population and the estimated benefits (lives saved) from PFDs. The linear relationship provides for the computation of the effects of changes in PFD parameters (wearability, accessibility, reliability, and effectiveness) on a victim's chances for survival. Basically, the relationship shows a benefit of approximately 8.8 lives saved for each 0.01 increase in the average LSI.

A graphical representation of the chronology of the Accident Recovery Model development is presented below.

CHRONOLOGY OF PROGRESS FOR THE ACCIDENT RECOVERY MODEL (ARM)



The development of ARM was an iterative process, based upon empirical data.

The ARM Analyst's Guide was written, along with needed computer programs.

The ARM sampling and weighting plan was designed to represent an "average" year.

The data were coded independently, verified by computer and analysts, and reviewed by senior project personnel.

The sampling and weighting plan was verified, the representativeness of the ARM data was checked. The results were analyzed, variable by variable, for the entire ARM data base.

Variable interrelationships were explored, results were provided for other parts of the PFD project, and complex analysis techniques were developed and used to evaluate the role of PFDs in boating accidents and the impacts of various existing and proposed USCG programs.

1.1 The Accident Recovery Model

The Accident Recovery Model (ARM) and techniques that were developed in conjunction with it are intended to provide the means for the Coast Guard to evaluate the role of PFDs in saving lives and to assess the impacts (in reducing fatalities) of many regulatory and educational programs. The model summarizes and organizes quantitative data concerning boating accident victims. By processing data from boating accident reports, marine inspection officer reports, in-depth investigations, and other sources, ARM captures all of the important aspects of the recovery system in the processes by which individuals live or die after boating accidents. The role of PFDs and their interrelationships with other factors (boater's behavior, weather, flotation, etc) are highlighted in ARM. ARM can be used to indicate problem areas in the recovery system, such as lack of PFD accessibility, lack of PFD wear, improper boater actions (leaving the boat, etc), and lack of flotation in the boat. ARM provides input to many parameters used in evaluating PFD effectiveness, wearability, and reliability. Techniques have been devised which can be used to provide estimates of potential benefits to be achieved via certain proposed regulations or educational programs, based upon ARM data. This section presents the research and findings in the three major functions of ARM: 1) to organize and summarize the accident data with respect to the recovery system, 2) to provide inputs to all phases of PFD evaluation, and 3) to provide measures and techniques for evaluating proposed Coast Guard programs.

In order to attain the goal of a common method of evaluating diverse PFD designs with regard to regulation, the impact of the PFD's lifesaving capability on preventing boating accident casualties must be investigated. This is why ARM is a general model, and goes well beyond PFDs alone. It reflects a deliberate attempt to create a data base that would be general enough to provide answers to a variety of questions. Obviously individual models or projects into specific problem areas (such as level flotation) will provide more detailed information and more accurate benefit estimates than ARM would for those same problem areas. However, ARM can summarize the accident data concerning many problems and their interactions.

Once the appropriate data have been processed, ARM can be used to generate quantitative estimates of the benefits associated with proposed or existing regulatory or educational programs. For example, ARM can help to provide answers to questions like the following:

1. How many lives are currently saved by PFDs annually?
2. What would be the effect of trade-offs in PFD characteristics, such as giving up some effectiveness while improving wearability?
3. Should PFDs provide greater protection against hypothermia? How many boaters die or become unconscious due to hypothermia annually?
4. What are the interrelationships between PFDs and other variables, such as water conditions, education, boat type, accident type, etc?
5. How might education increase recovery? For example, is the maxim "stay with your boat" always the best course of action?
6. How might level flotation affect the role of PFDs in accident recovery?
7. How many adults are incapacitated while in the water, requiring self-actuating and/or self-righting PFDs?

During the formulation of ARM, three general methodological principles or objectives emerged. These three principles gave direction to the development of the model and helped to insure that the final product was useful.

The first of these principles was that the model must be empirical. It is based upon documented cases of recovery or fatality in recreational boating accidents rather than assumption or expert opinion. By building the model on an empirical base, one can have greater confidence that the result is a valid representation of the way recoveries and fatalities actually occur. ARM involves relatively few assumptions. Furthermore, these assumptions were checked and modified as needed as additional data were gathered. ARM can be regarded as a structured summary of boating accident recovery data.

A second principle was that ARM must summarize the common elements in accident recovery, while at the same time not sacrificing important relationships. It must be developed at an appropriate level of generality. In any type of modelling or analysis problem, there is a trade-off between summarization and representing detail. At one extreme, the average number of fatalities per accident could be regarded as a model. Obviously, this method sacrifices too much detail for an overall summary. The other extreme would be a detailed account of each of the accidents which occurred, say in 1974. This alternative doesn't sacrifice any details, but fails to point out commonalities among accident recoveries or fatalities. The model was developed in such a way as to capture important relationships among elements of the accident recovery system that are common to many accidents.

The third criterion for ARM was that it must be in a form which is usable by the Coast Guard. This means that events or conditions which the Coast Guard can control by regulation, standards, or eduction must appear as elements of the model. This criterion also implies that the model must make use of existing accident data, even though such data is often incomplete and not representative of the population of boating accidents to be modeled.

The ARM report is divided into six subsections. The first (2.0) deals with the development of the Accident Recovery Model. This development is summarized briefly, and the refinements that have occurred since the conclusion of Phase I (see Reference 1) of the PFD project are highlighted. Subsection 3.0 presents the sampling plan for ARM (how the data were selected) and describes the relationship between the sampling plan and the weighting plan for the data. The ARM data are weighted so a relatively small number of victims in ARM can be used to represent a larger number of accident victims in the real world. The next subsection (4.0) discusses the details of the model, the coding instructions, the verification process, and the basic results. Subsection 5.0 includes data analysis involving combinations of variables relating to the circumstances associated with PFD use and other analyses. This subsection shows some of the ways that ARM can be used to provide answers for questions, such as those listed previously. Then 6.0 presents detailed benefit calculations for several specific problems. The computationsin this subsection are the type that might be done in order to analyze the effects of proposed or existing Coast Guard regulations or programs. Finally, subsection 7.0 describes the conclusions of the ARM section, and the relationship of ARM to other tasks in the PFD project.

2.0 ARM DEVELOPMENT

2.1 Method

The following pages review the various types of models and conceptual structures considered during the development of ARM, culminating in the ARM discussed in Section 4.0. For additional details on previous versions of ARM, the reader is referred to the PFD Phase I final report (Reference 1).

Work on the accident recovery problem began with the consideration of the many factors which could affect the probability of recovery of a victim of a boating accident. The term "victim" refers to anyone involved in the accident regardless of whether the person survived or died. The first step was the compilation of a structured list of such factors. This list considered three general categories of variables: (1) environment, (2) behavior and condition of the victims, and (3) equipment. The latter two categories were further subdivided into variables which were pre-existing or measurable well before the accident, and short-term factors which are measurable only at the time of the accident or afterward.

It is clear that accident recovery can be regarded as a time-dependent probabilistic process. The problem is complex, since the probabilities depend upon a multitude of factors and since these factors may not be statistically independent or mutually exclusive. Several types of models were considered to model the recovery process.

Fault trees and decision trees were constructed in attempts to model the recovery of a boating accident victim as a probabilistic process. The advantages of these approaches were that they showed how the probability of recovery was related to measurable quantities at end nodes (such as the probability that a victim can tread water), and the strengths of interrelationships (paths through the tree) were indicated by merely counting the frequencies of occurrence in the data. The problem with these types of models was that the interrelationships were determined logically (or on the basis of expert knowledge) rather than empirically. In addition, if a decision at an early node in a tree cannot be made, information for lower nodes (which may be known) is lost because the victim cannot be processed beyond the unknown decision point.

One large decision tree that was developed was tested with accident data. A sample of accidents was processed. The pilot test of the decision tree approach

showed that 1) much information was lost because unknowns were encountered at early decision nodes, and 2) there were many victims who seemingly skipped around within the tree, indicating that a tree which captured all possible interrelationships between variables would have to be immense. Such a "tree" would be equivalent to the matrix or list approach to the model. If each node branched to many possible, successive nodes for a decision tree, that would be virtually the same as merely making the successive decisions independently. To illustrate, consider the tree model in Figure VI-1, as opposed to the list or matrix model in Figure VI-2. Of course, the preliminary ARM models were much larger; those in the figures are merely for illustration.

As can be seen from the figures, if the tree model is forced to contain all possibilities under each node then it conveys no more, or less, information than the list or matrix model; i.e., each model has eight possible resultant codings with exactly the same meanings. Large trees, such as would be required in ARM, are cumbersome. In addition, the list or matrix approach allows information to be coded despite an "unknown" to a previous question. In the tree in Figure VI-1, if we did not know if the victim entered the water, but did know he wore a PFD, we have no way to code the known information.

As a result of these considerations, the final version of ARM was constructed as a list or matrix type of model. ARM organizes and summarizes accident data. It generates a structured, manipulable data base. Data are processed using a list of questions with coded responses and a collection of small decision trees which allow the accident analyst to categorize a given victim's behavior and environmental circumstances (boat condition, PFD use, etc).

To summarize, the method employed in the development of ARM was an iterative process. Elements of the model were formulated and evaluated by consultation with the boating accident data. General properties of the model were derived to fit the data base problems and the Coast Guard's needs. The list or matrix model presented below is a result of the refinement of earlier models, and remnants of fault trees and decision trees used previously remain in portions of ARM.

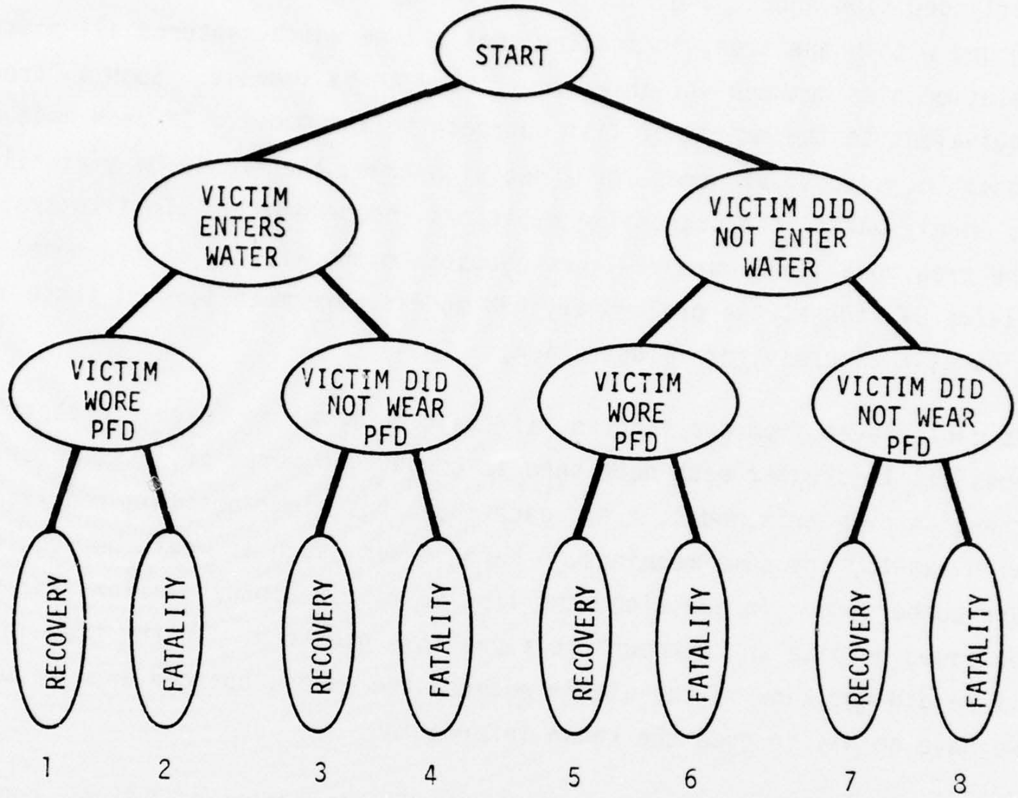


FIGURE VI-1. ILLUSTRATIVE TREE MODEL

DID VICTIM ENTER WATER?	1 = Yes; 2 = No	
DID VICTIM WEAR A PFD?	1 = Yes; 2 = No	
DID VICTIM DIE?	1 = Fatality; 2 = Recovery	
POSSIBLE CODES:	111	211
	112	212
	121	221
	122	222

FIGURE VI-2. ILLUSTRATIVE LIST/MATRIX MODEL

2.2 Results

The Accident Recovery Model consists of an analyst's guide (instructions for coding accidents and quality assurance procedures) and coding sheets. These materials were used to code a sample of over 1500 boating accident victims and to generate the ARM data base. The ARM Analyst's Guide is shown in Appendix VI-A. The coding sheet for ARM data is shown in Figure VI-3. Each row on the coding sheet contains the coded information for a single individual (boating accident victim) in ARM. The numbers and words across the top of the coding sheet indicate the variable number and variable name in the analyst's guide for that column or columns on the sheet.

ARM has been expanded to include more information, and some of the instructions in the analyst's guide have been modified since the completion of Phase I (see Ref. 1). Variables 41 through 51 have been added to ARM. These variables, in addition to a few other changes in the coding instructions, will be discussed in the following paragraphs. Other parts of the model remain as they were at the conclusion of Phase I. The sample that was coded into ARM is discussed in the next section, and the coding and verification methods are discussed in Section 4.0. The remainder of this section is devoted to describing the new aspects of the analyst's guide since the completion of Phase I.

Variable 41 identifies whether the vessel for a particular victim had a known hull identification number. This new variable, along with variables 42 through 51, was only coded for the data processed in Phase II, and not coded for accidents processed in Phase I. If the Federal Boat Documentation Number was given, then variable 41 was coded as "known." The year of manufacture of the boat (model year) was coded as variable 42.

The number of PFDs of each type (type I, type II, unapproved, etc) that was known to have been aboard was coded in variables 43 through 49. These data were collected in order to provide information concerning the population of PFDs in accidents, and to provide wear rate data for different types of PFDs. (The type that was worn, if any, was coded in variable 33.)

The type of power and alcohol information were the final two variables coded (variables 50 and 51). The powering variable was included because of its

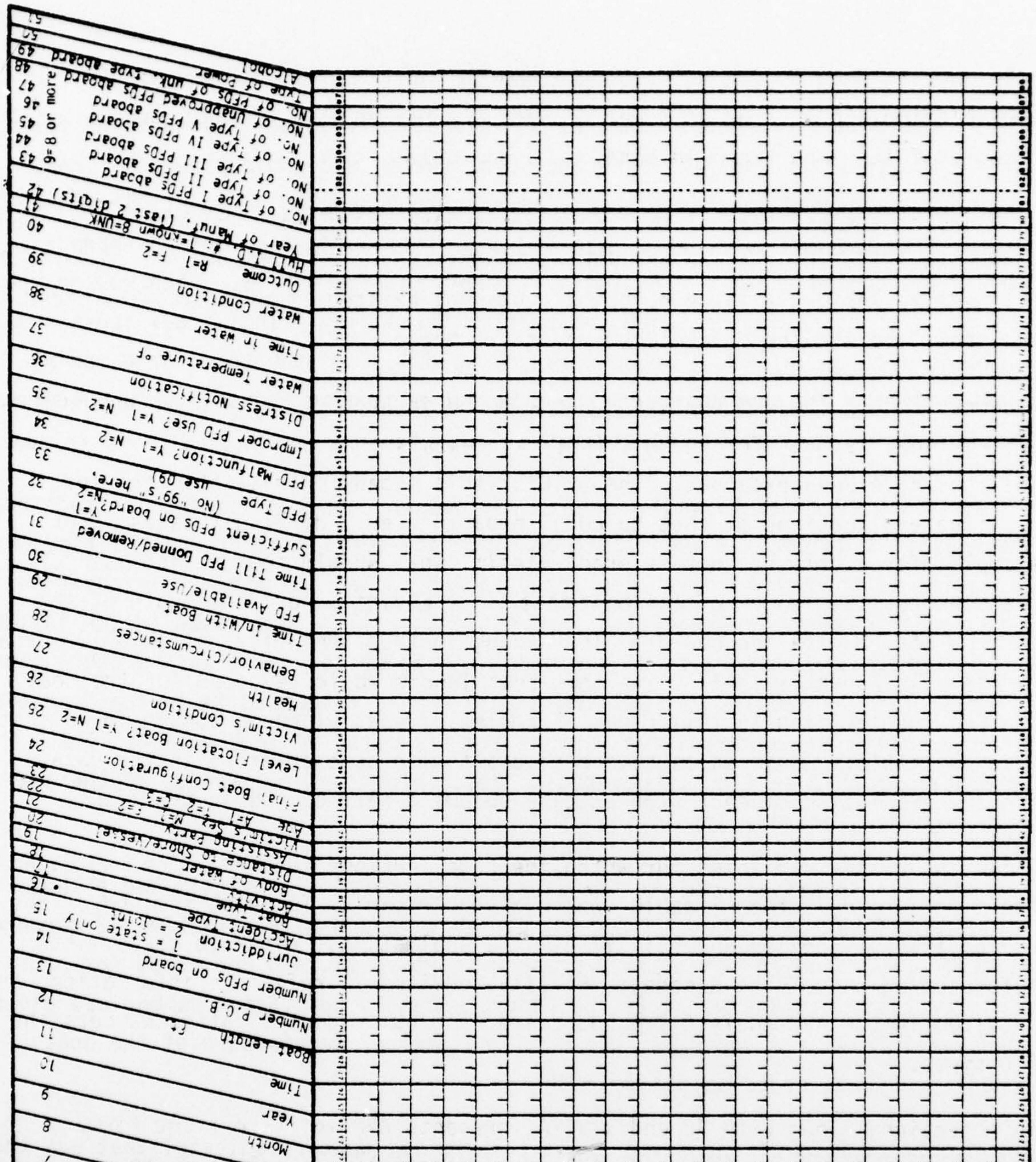


FIGURE VI-3. ARM CODING SHEET

relevance to ongoing Coast Guard research in powering, and to provide data on the relationship of type of power to recovery variables. Alcohol was included because of its importance in behavior and victim's circumstance variables.

With all of the new variables, however, the data are known only for the accidents coded in 1977, and not for the ARM accidents that were coded earlier. For all of these variables, a large number of unknowns existed (from previously coded accidents) before the current coding effort began.

A comparison of the ARM Analyst's Guide found in Appendix VI-A with Appendix I-A of the final report for Phase I (Ref. 1) reveals that the instructions to the data analysts have been expanded. The bulk of this expansion has taken the form of detailed explanations of what to code in particularly difficult cases. For example, for a "hit by boat or prop" victim, what should the analyst use for boat length, the length of the boat that hit the victim, or the length of the boat he may have fallen out of? The coding instructions (for variable 12 - Boat Length - in Appendix VI-A) state that boat length would be coded for the boat that did the hitting in this case. Examples of special cases abound for almost every variable. These cases have been dealt with as they arose in the data, and the resolution of each problem case became a part of the instructions.

A listing of the variables for which the code "unknown" was not acceptable, and those for which "not applicable" was acceptable can be found at the end of the coding instructions in Appendix VI-A. The analyst must refer to these lists before using one of these codes. Finally, additional reference information was provided in the ARM Analyst's Guide concerning hull identification numbers and PFD types.

This section, along with Appendix VI-A, presents ARM in its current form. Succeeding sections discuss how the ARM accident sample was selected, how the data processing was accomplished, and the results of coding the accident data.

3.0 DATA SELECTION

3.1 Method

It would have been impractical and costly to have coded all the accidents for a given year into ARM. And yet, ARM is supposed to be representative of a year's worth of accident data. The solution was to sample a subset of the accidents and weight them (multiply each datum by a weighting factor) in order to make the summary accident statistics for the ARM data match the statistics for a typical year's worth of data. Thus, the sampling plan (the method for selecting the accidents for ARM) and the weighting techniques (used to project the sample to match a year's worth of data) are intimately related.

The first step in setting up the sampling plan was to determine the total size of the sample and compare this to the overall population it would represent. In Phase I, 477 cases were sampled from the Coast Guard's files of boating accident reports from 1969 through 1975. These cases were chosen according to a sampling plan that attempted to match the frequency distribution of the joint occurrence of particular boat types and accident types in the ARM sample to the frequency distribution in CG-357 (averaged over 1972-1974). It must be remembered that the Phase I sample was selected in order to demonstrate ARM and related statistical techniques, and not to provide a finished ARM data base. Each individual ARM victim was then weighted in Phase I, so that the total number of recoveries and fatalities after weighting would match the Coast Guard's statistics. Since the sampling was designed on an accident-by-accident basis, and the weighting was done on individuals, biases arose in the data base for Phase I. Most of the biases were toward having a higher percentage of fatalities (and, therefore, more severe circumstances) than would be expected based upon CG-357. The biases were deliberate, and were introduced in order to adequately test ARM. The fatal accidents generally contained a lot of information and produced data that were coded in all parts of the model. The biases in the data were evidenced by the individual weightings, ranging from 1.32 to 137.21. This means that some individuals in the Phase I sample represented 1.32 (each) people from the overall accident population, while others represented 137.21 people. Reducing the biases and obtaining a better overall sample (more representative) were the objectives of the sampling plan and weighing plan for ARM in Phase II. Attaining these objectives would correspond to weights that were relatively small and consistent (weights that did not differ significantly).

The ARM data have been sampled to be representative of the Coast Guard's year end data for 1975 (after the data processing of Phase II). This year was chosen because it was the most recent data available, and Coast Guard personnel felt that the year end data from 1975 were perhaps the most reliable available. The year end data include a few data points that are processed after the publication of CG-357 for a given year, and the 1968 through 1974 data required recoding in order to improve their reliability. Thus, the data that the ARM data match after weighting is the accident data for 1975. In areas where anomalies may have existed fortuitously in the 1975 data (no fires on sailboats, for example), the data for the previous eight years were averaged to generate a representative number for the ARM data to match.

According to the work statement for Phase II, 300 accidents were to be processed in addition to those coded in Phase I. These accidents were chosen to include recoveries and fatalities in numbers that would reduce the weights needed to match the Coast Guard data (thereby assuring representativeness) and make the various weights be of the same magnitude (thereby eliminating biases on the variables used for weighting). Since the fatal accidents are those with the greatest potential for benefits, and provide more information, in general, than nonfatal accidents, fatalities were arbitrarily assigned a criterion weight of 10 or less, while a criterion weight of 20 or less was assigned to recoveries. This means that the sample was to be chosen so that after the Phase II and Phase I data were combined, no fatality in ARM would represent more than 10 fatalities in the Coast Guard's year end data for 1975. Similarly, no recovery in ARM would represent more than 20 recoveries in the year end data. These criteria were chosen because they were obtainable with the sample size of 300 accidents, and the data for fatalities were considered to have greater potential for generating data that could lead to significant safety measures (thus, a lower criterion weight was set for fatalities than for recoveries).

The Phase I ARM data were tabled according to boat type crossed with accident type, for recoveries and fatalities. These data were then compared with the numbers that would be required in order to have the desired weighting. For example, if the Coast Guard's year end data for 1975 showed 41 fatalities for cabin cruisers and houseboats in capsizings and swampings, then, for each ARM victim to represent no more than ten of the 41, there would have to be at least

five ARM fatalities involving cabin cruisers and houseboats in capsizings and swampings ($41 \div 5 < 10$). In fact, the ARM data from Phase I included seven fatalities in this set of circumstances. Thus, the sampling plan for Phase II required no additional fatalities to be sampled for cabin cruisers and houseboats in capsizings and swampings. Similar calculations were made for all combinations of boat type, accident type, and outcome (recovery versus fatality). The results constituted the sampling plan for Phase II, and are shown in Tables VI-1 and VI-2. Each entry in these tables is the number of fatalities or recoveries needed in the Phase II sample in order to satisfy the criteria described previously. Obtaining more than the needed number in any cell of the tables would result in an even lower weight for that cell, thereby increasing its representativeness. Tables VI-3 and VI-4 reoresent the data that the ARM data are weighted to match. The numbers are decimals because the Coast Guard data contained unknowns, which were redistributed assuming the distribution of the known data. This was done so the total number of fatalities and recoveries in ARM would match the Coast Guard data, including those that were unknown for accident type and for boat type in the Coast Guard data.

Over 99% of the data included in Phase I were sampled from years prior to 1975. To avoid coding any of those accidents again in Phase II, the accidents were sampled from the 1975, 1976, and 1977 files. These accidents were sampled from all geographic regions until the required numbers of fatalities and recoveries for various boat type/accident type combinations were obtained. This was accomplished with less than 300 accidents. The remainder were sampled randomly.

Some additional explanation is required for parts of Table VI-4. For all accidents types except falls overboard, hit by the boat or prop, and other, the total number of recoveries in the Coast Guard data (or in ARM) is found by subtracting the number of fatalities from the number of people on board. This is because for collisions, capsizings, swampings, fires, and the like, everyone on board is a victim of the accident (i.e., everyone is a participant and subjected to risk). For falls overboard, hit by the boat or prop, and some "other" accidents, not all of the people on board are participants. Many people on boats in these types of accidents are merely witnesses and are never subjected to any risk. They are not considered as boating accident recoveries in ARM, since they had no accident from

TABLE VI-1. NUMBER OF FATALITIES NEEDED TO MATCH CG DATA WITH ALL FATALITY WEIGHTS LESS THAN 10

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	3	1	2	Empty	1	1
Open Power	14	OK	16	OK	OK	1
Cabin Cruiser/ Houseboat	OK	OK	3	OK	1	2
Sail/Auxiliary Sail	4	OK	2	OK	1	OK
Canoe/Kayak	11	1	1	Empty	Empty	2
Other	4	OK	2	1	1	2

NOTE: Cells labelled "OK" are those where the ARM sample from Phase I was large enough to guarantee a weight less than 10. Cells labelled "empty" are those where there have been no deaths reported to the Coast Guard in the last eight years.

TABLE VI-2. NUMBER OF RECOVERIES NEEDED TO MATCH CG DATA WITH ALL RECOVERY WEIGHTS LESS THAN 20

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	OK	5	OK	1	1	1
Open Power	24	181	OK	13	OK	33
Cabin Cruiser/ Houseboat	8	85	1	11	1	10
Sail/Auxiliary Sail	6	72	OK	OK	1	6
Canoe/Kayak	3	2	1	OK	OK	1
Other	2	5	3	2	1	2

NOTE: Cells labelled "OK" are those where the ARM sample from Phase I was large enough to guarantee a weight less than 20.

TABLE VI-3. FATALITY DATA TO BE MATCHED BY WEIGHTED ARM DATA

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	103.75	3.44	32.37	0.00	0.13	8.54
Open Power	420.15	142.96	232.76	7.42	13.58	41.74
Cabin Cruiser/ Houseboat	40.97	19.56	37.19	4.12	0.50	16.33
Sail/Auxiliary Sail	42.69	5.66	21.66	0.13	1.14	15.46
Canoe/Kayak	136.54	12.61	5.77	0.00	0.00	15.63
Other	80.37	11.56	19.79	1.10	1.17	10.95

NOTE: Those cells with entries less than one represent the average number of fatalities in the cell over the last eight years. The other entries are for the Coast Guard's year end data from 1975.

TABLE VI-4. RECOVERY DATA TO BE MATCHED BY WEIGHTED ARM DATA

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	106.41	104.35	14.96	3.14	1.00	12.13
Open Power	1561.74	7109.87	453.10	684.91	105.87	934.13
Cabin Cruiser/ Houseboat	416.87	3510.75	125.82	639.07	5.00	239.44
Sail/Auxiliary Sail	164.21	2255.68	23.37	25.53	1.86	131.93
Canoe/Kayak	135.85	85.13	16.96	0.00	0.00	1.88
Other	148.70	187.75	57.19	48.92	6.83	31.67

which to recover. Therefore, the formula of people on board minus fatalities will not generate the number of recoveries for these accident types. The Coast Guard data for these accident types contains only the number of fatalities and the number of people on board, but not the number of people actually involved in the accident. This makes an accurate estimate of the total number of recoveries in these accidents impossible based upon these data alone.

For hit by the boat or prop, it is very rare that one vessel hits more than one person in the water. Over the past five years, the sum of the number of fatalities from hit by the boat or prop equals the sum of the number of boats involved in fatal accidents of that type, indicating a strong one-to-one relationship. Thus, the number of vessels involved in nonfatal hit by the boat or prop accidents was used as an estimate of the number of recoveries in those accidents.

The problem of estimating recoveries is not as easily solved for falls overboard and "other" accidents. For falls overboard, there are more fatalities than boats in the Coast Guard data. This indicates that frequently more than one person per boat is falling overboard, but it is impossible to know how many from these data. What is known is how many die.

Several methods of estimating recoveries for falls overboard and "other" accident types were investigated. However, all of these methods suffered from the fact that the ARM sample sizes in these accident types would be relatively small, and when the data were weighted to match a full year's data, there would be no yardstick in the Coast Guard data base for comparison. The method that was implemented was to use the people on board minus fatalities as the criterion to be matched. This is essentially the same method as was used for all the other accident types except hit by the boat or prop. The method is equivalent to assuming that the percentage of the surviving people on board who were actually involved in the accident is the same in the whole population, as it is in our sample. It should be realized that the resulting estimates for recoveries in these accident types are rough estimates at best.

In summary, accidents were to be sampled for Phase II such that the desired number of fatalities and recoveries shown in Tables VI-1 and VI-2 were included in the sample. This would insure that criteria for weighting the data would be met.

3.2 Results

Over three thousand boating accident reports were screened in order to select the three hundred for processing in Phase II. To assure geographic representativeness, every tenth accident report was read and screened from the entire Coast Guard files for 1975. Then the files were re-examined accident by accident in order to find the elements of the sampling plan which were not completed in the initial screening. A total of approximately 210 accidents were selected which satisfied most of the elements of the sampling plan. Later, an additional sample of accidents was selected from the 1976 and 1977 data to bring the total sample size to 300 accidents.

Tables VI-5 and VI-6 below show the numbers of recoveries and fatalities in the ARM data (unweighted) for each combination of accident type and boat type after the data from Phase I and Phase II were combined. The numbers in the parentheses in the recovery table are the people on board for those cells. Recall from the previous discussion that people on board minus fatalities was used to determine the weights in these cells. The recoveries in these cells (the numbers outside the parentheses) were to be multiplied by the weights. Note that for some cells (falls overboard involving open power boats, for example) the number of fatalities (27) plus the number of recoveries (28) is less than the total people on board (80). This demonstrates that not all people on board were involved in the accidents (in this case, 25 people were on board open power boats in falls overboard, but never became involved in the accidents).

The data in these tables and Tables VI-3 and VI-4 were used to generate the weights for the ARM data. The fatality weights were determined by dividing the number of fatalities in the Coast Guard year end data for 1975 for a particular combination of boat type and accident type (from Table VI-3) by the number of fatalities in the same cell for the ARM data (from Table VI-5). For example, there are 41.74 fatalities in Table VI-3 for open power boats in "other" accidents, and there are ten fatalities (unweighted) in ARM in this cell, as shown in Table VI-5. The fatality weight for these ten is calculated by dividing: 41.74 ÷ 10 = 4.17. The fatality weights are presented cell by cell in Table VI-7. Inspection of Table VI-7 reveals that the goal of the sampling plan with respect to fatalities (having all fatality weights less than ten) was achieved. The exceptions to this statement were those cells where the Coast Guard data indicated fatalities did occur, but none, or not enough, were sampled in the ARM data. In order to eliminate the exceptions (the starred cells and those with fatality weights greater than 10), the entire Coast Guard data base would have to be scanned to find the unusual accidents which fit those categories.

TABLE VI-5. TOTAL FATALITIES (UNWEIGHTED) IN ARM DATA BASE

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	13	1	4	0	0	3
Open Power	50	64	27	5	2	10
Cabin Cruisers/ Houseboats	9	16	4	7	0	7
Sail/Auxiliary Sail	7	3	3	1	0	3
Canoe/Kayak	17	1	1	0	0	0
Other	10	3	3	0	1	2

TABLE VI-6. TOTAL RECOVERIES (UNWEIGHTED) IN ARM DATA BASE

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	14	10	5(9)	0	0	0(3)
Open Power	81	435	28(80)	29	16	41(89)
Cabin Cruisers/ Houseboats	48	196	3(24)	26	0	9(34)
Sail/Auxiliary Sail	6	189	2(7)	9	0	5(8)
Canoe/Kayak	26	5	0(3)	0	0	0(0)
Other	11	28	2(16)	1	1	2(4)

NOTE: The numbers in parentheses are the total people on board in the indicated combinations of boat type and accident type.

AD-A058 738 WYLE LABS HUNTSVILLE ALA F/G 6/7

PERSONAL FLOTATION DEVICES RESEARCH. VOLUME 2. RESEARCH REPORT.(U)

JAN 78 T DOLL, M PFAUTH, J GLEASON, S COHEN DOT-CG-42333-A

UNCLASSIFIED MSR-78-1-VOL-2 USCG-D-41-78-VOL-2 NL

5 OF 6

AD A058738

5 OF 6

AD
A058738

TABLE VI-7. ARM FATALITY WEIGHTS

ACCIDENT TYPE / BOAT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	7.98	3.44	8.09	0.00	0.00*	2.85
Open Power	8.40	2.23	8.62	1.48	6.79	4.17
Cabin Cruiser/ Houseboat	4.55	1.22	9.30	0.59	0.00*	2.33
Sail/Auxiliary Sail	6.10	1.89	7.22	0.13	0.00*	5.15
Canoe/Kayak	8.03	12.61	5.77	0.00	0.00	0.00*
Other	8.04	3.85	6.60	0.00*	1.17	5.48

*NOTE: For these cells, the Coast Guard data indicate that fatalities exist, but none were sampled in the ARM data base.

Recovery weights involve more complicated calculations. For all accident types except falls overboard, hit by the boat or prop, and "other", the total people on board minus the fatalities in the Coast Guard data for a given combination of accident type and boat type, divided by the total people on board minus fatalities in the ARM data, determine the recovery weights shown in Table VI-8. For example, Table VI-4 shows 106.41 recoveries in the Coast Guard data for capsizings/ swampings involving open manual boats. Table VI-6 shows 14 recoveries in ARM for that cell. The recovery weight for that cell is $106.41 \div 14 = 7.60$, as shown in Table VI-8. For hit by the boat or prop, the entries in Table VI-4 were again divided by the corresponding entries in Table VI-6 to generate the recovery weights in Table VI-8, but the entries in Table VI-4 were the number of <u>boats</u> of each type involved in nonfatal accidents of this type, as explained previously. For falls overboard and "other" accidents, the ratio of people on board minus fatalities for the Coast Guard data to the same quantity in the ARM data is used, cell by cell, to generate the weights in Table VI-8 for those accident types, but the weights are only applied to the actual recoveries in ARM (the numbers outside the parentheses in Table VI-6).

TABLE VI-8. ARM RECOVERY WEIGHTS

BOAT TYPE \ ACCIDENT TYPE	CAPSIZINGS/ SWAMPINGS	COLLISIONS/ GROUNDINGS	FALLS OVERBOARD	FIRE/ EXPLOSIONS	HIT BY BOAT OR PROP	OTHER
Open Manual	7.60	10.44	2.99	0.00*	0.00*	0.00*
Open Power	19.28	16.34	8.55	23.62	6.62	11.82
Cabin Cruiser/ Houseboat	8.68	17.91	6.29	24.58	0.00*	8.87
Sail/Auxiliary Sail	27.36	11.93	5.84	2.84	0.00*	26.39
Canoe/Kayak	5.23	17.03	8.48	0.00	0.00	0.00*
Other	13.52	6.71	4.40	48.92	6.83	15.84

*NOTE: For these cells, the Coast Guard data indicate that recoveries exist, but none were sampled in the ARM data base.

Table VI-8 reveals that the sampling criteria for recoveries were met for 26 of the 36 cells, the weights exceeded 20 because not enough recoveries were located and sampled. This was particularly a problem for fires and explosions. However, for four of those five cells, the weights were in the twenties (close to criterion), and none of the weights were as large as they had been in Phase I (where recovery weights reached a maximum of 137.21). For five cells, no recoveries were sampled in ARM, but the Coast Guard year end data indicated that recoveries existed. A weighting of zero was assigned to these cells.

In order to get all recovery weights under 20, and in order to get non-zero recovery weights for the starred cells, the entire Coast Guard data base would have to be scanned to find the accidents which fit those categories.

A total of 1,513 individuals are included in the overall ARM sample. The sample includes 1,236 recoveries and 277 fatalities, representing an estimated 18,325 recoveries (per year) in the boating accident population, and 1,489 fatalities. This makes the overall probability of recovery in ARM 0.925 (= 18,325 ÷ 19,814) On the average, each recovery in ARM represents approximately 14.8 recoveries in the boating accident population, while each fatality in ARM represents approximately

5.4 fatalities in the Coast Guard year end data. The weighting allows the ARM data to be projected as a representation of all boating accidents.

Further indications of the representativeness of the ARM data will be presented in the next section, which discusses the coding and verification process, and presents the basic results of the ARM coding.

4.0 DATA PROCESSING

4.1 Method

The 300 accidents to be coded were grouped into batches of approximately fifty accidents per batch. Two analysts were assigned to each batch to code the accidents independently using coding sheets (such as in Figure VI-3) and according to the instructions found in the ARM Analyst's Guide (Appendix VI-A). Senior project personnel were available to help the analysts with coding problems and the interpretation of the coding instructions. Once all the accidents from a given batch were coded by both analysts, the data on the coding sheets were keypunched onto computer cards, independently for each analyst. A computer program was then used to compare the two sets of coded data and check for discrepancies. The discrepancies were then resolved by a third analyst, who read the same accident reports and identified the correct codes for variables where disagreement occurred between the first two analysts. The third analyst also verified all codes for the two sets of coded data, consulting with the two original coders and senior project personnel as needed. The third analyst made written corrections to each of the two sets of coded data and returned them to have the corrections keypunched. The coded decks of computer cards were compared again. The process was repeated until the two sets of data were identical. At this point, senior project personnel selected a small sample of accidents (approximately 10 percent of the batch) and verified them, to insure that no errors or misinterpretation of the instructions had occurred. If problems with the codings were found by the project leaders, then these problems were discussed with all ARM analysts to make sure that future data processing was performed correctly. The only way that an error in keypuching or primary coding could have survived this system would be if the same mistake were made simultaneously and independently by more than one person on the same accident. The coding and verification process can be conceived in the form of the flowchart shown in Figure VI-4. The process depicted in the flowchart was repeated until all 300 accidents had been coded and verified.

Coding the accidents for ARM was far from a trivial exercise. Although ARM is a general model, some of the more unusual accidents that were coded created difficult coding problems. The coding of these accidents often resulted in the amendment of the ARM Analyst's Guide by expanding the instructions to include special cases.

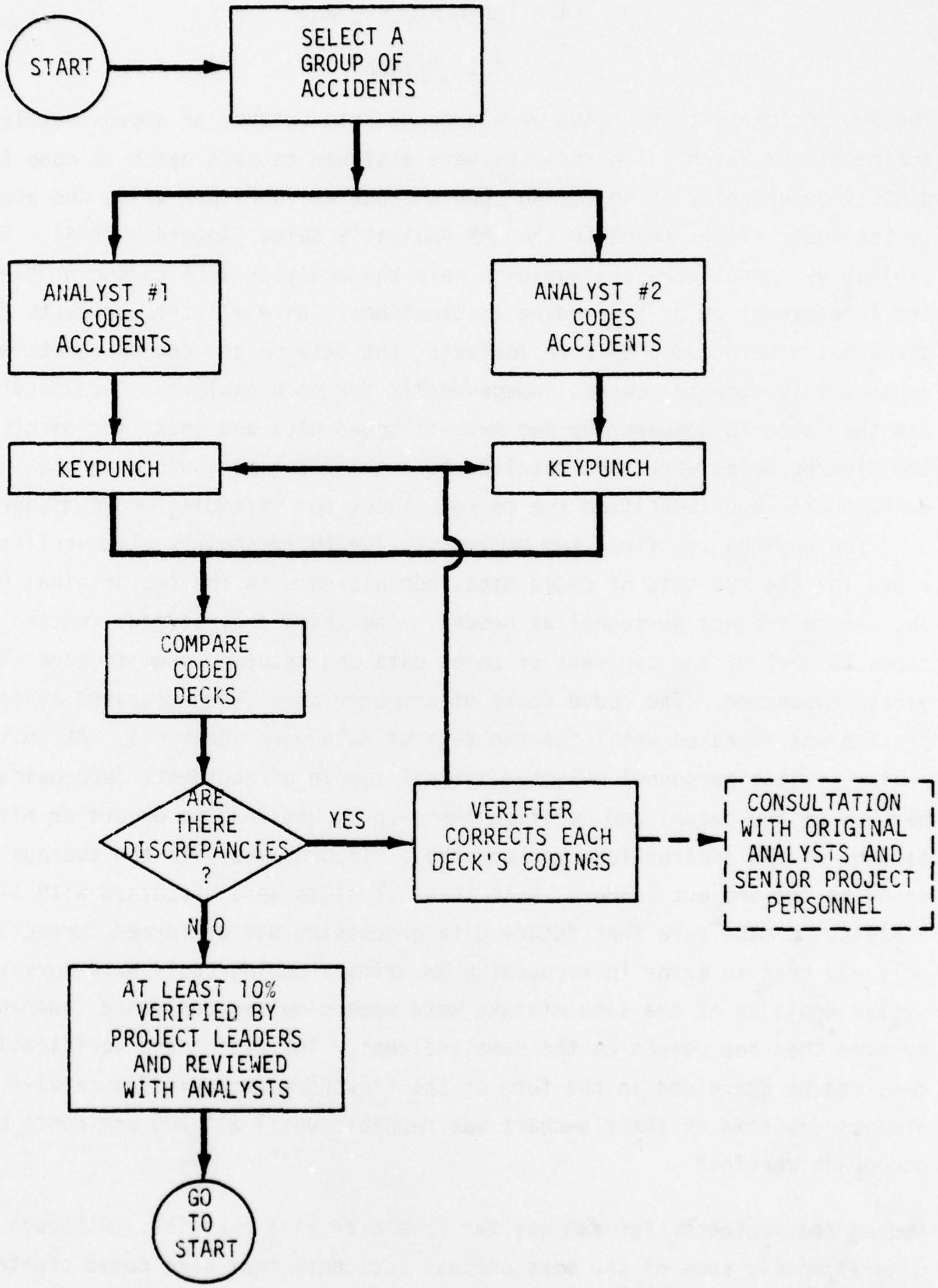


FIGURE VI-4. ARM CODING AND VERIFICATION PROCEDURES

4.2 Results

This section presents the weighted ARM data for many of the 51 variables in the model. Several of the first tables include data from CG-357 for 1975 to show the representativeness of the ARM data. Later tables include data for issues related to PFDs, as well as other Coast Guard programs.

4.2.1 Results: Representativeness of ARM Data

Figure VI-5 shows the ARM accidents and overall accidents (from CG-357) for each of four geographic regions. The distribution of the ARM victims differs somewhat from the distribution of accidents in the Coast Guard data. Of course, the ARM data were sampled according to criteria other than geographic location, as outlined in Section 3.0.

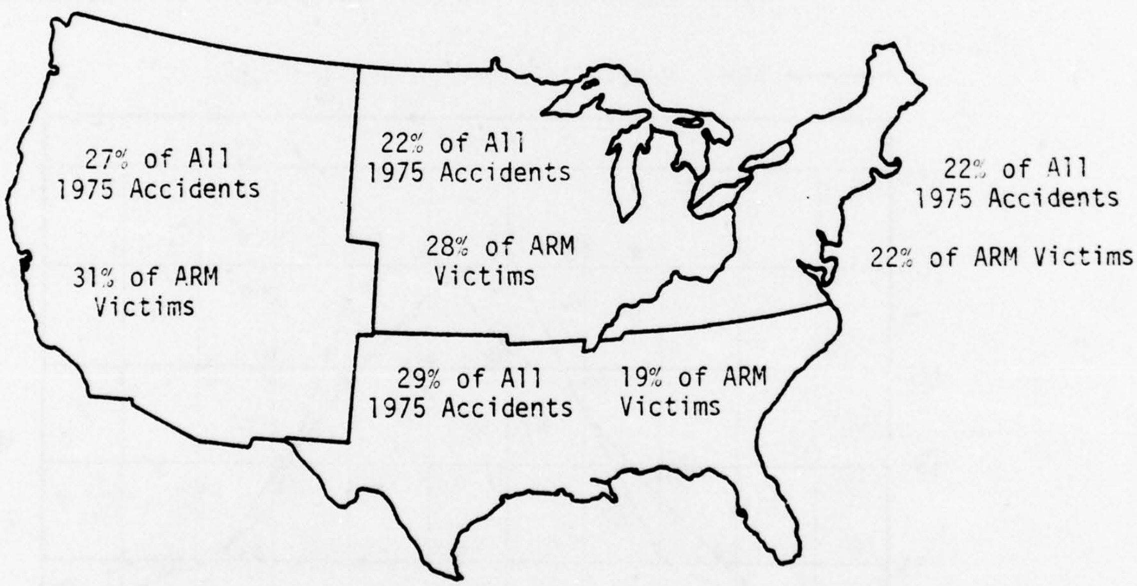


FIGURE VI-5. ACCIDENTS BY GEOGRAPHIC REGION FOR 1975 AND ARM

The distribution of the ARM victims by month and time of day for their accidents are shown in Figures VI-6 and VI-7, respectively. Figure VI-6 shows that the peak month for ARM victims is June. This corresponds to the peak month for vessels involved in fatal accidents in 1975 (see CG-357 for 1975). The ARM data for time of day (see Figure VI-7) correspond well with the Coast Guard data.

Figure VI-8 shows that the ages of the boats in the ARM sample (as shown by the year of manufacture of the boat) match well with similar data from CG-357 for 1975.

To conclude the representativeness results, the ARM victims are tabulated by the year of their accidents in Table VI-9. These figures reveal that nearly half of the ARM victims were from 1975 accidents, and the remainder were from accidents from 1969 to 1977.

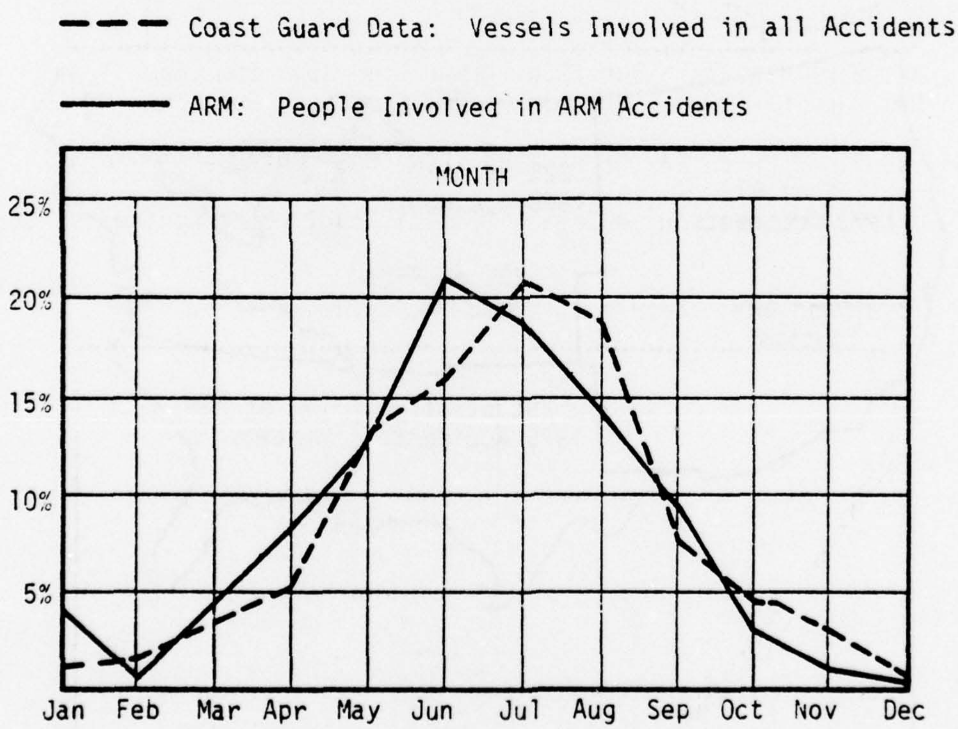


FIGURE VI-6. MONTH OF OCCURRENCE FOR COAST GUARD AND ARM DATA

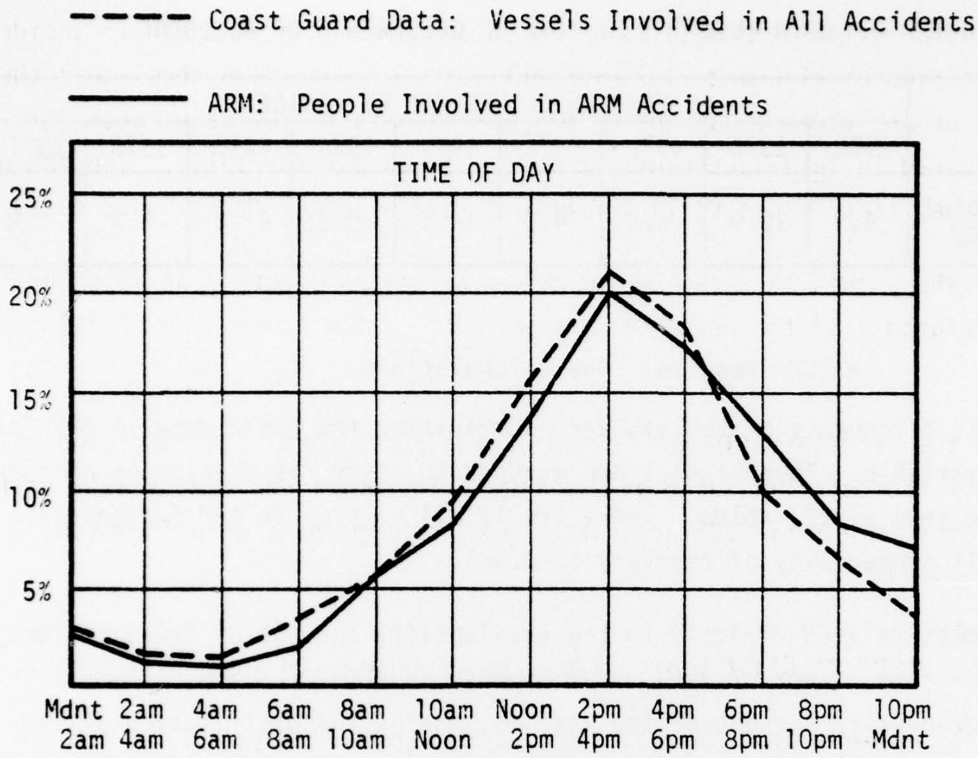


FIGURE VI-7. TIME OF DAY OF ACCIDENT FOR COAST GUARD AND ARM DATA

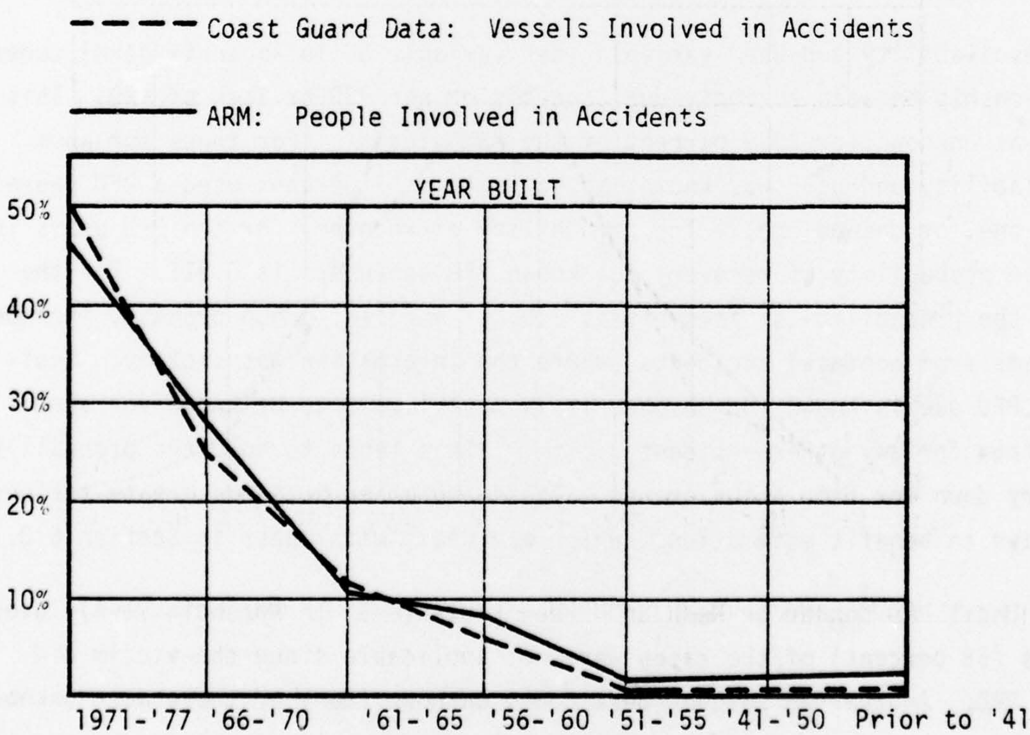


FIGURE VI-8. YEAR OF MANUFACTURE OF BOAT
FOR COAST GUARD AND ARM DATA

TABLE VI-9. ARM DATA (VICTIM) BY YEAR OF OCCURRENCE OF ACCIDENT

	YEAR OF OCCURRENCE OF ACCIDENTS								
	1969	1970	1971	1972	1973	1974	1975	1976	1977
Percent of Total Victims in ARM	4.9	10.9	6.0	4.0	14.5	0.8	47.5	5.3	5.8

4.2.2 Results: Basic Tabulations

What follows is a sequence of tables, each summarizing the basic data in ARM for a particular variable. These tables are grouped to unify the discussion of issues that relate to several variables. There are 19,814 victims in ARM (weighted) with an overall probability of recovery of 0.925.

Several variables related directly to the availability and use of PFDs, but many of these suffer from a lack of data. For "Number of PFDs On Board," the variable was unknown for over 82 percent of the victims, making the distribution of the remaining 18 percent almost meaningless, although there is a trend for the probability of recovery to increase with more PFDs on board in the known data.

The "PFD Availability and Use" variable (see variable 30 in Appendix VI-A) codes the relationship between an individual and his or her PFD or lack of PFD. This variable was unknown for 29.9 percent of the ARM victims. For those for whom "PFD Availability and Use" was known, approximately 17 percent used a PFD (wore one, held one, or donned one). The probability of recovery for the PFD users is 0.914. The probability of recovery for known PFD non-users is 0.911. For the unknowns, the probability of recovery is 0.962. The last group probably includes many victims from nonfatal accidents, where the information was sketchy. Typically, if PFD use is known for anyone, it is more likely to be known for the fatality than for any other accident victim. This tends to hold the probability of recovery down for both known groups. These and other problems create serious difficulties in benefit estimations, which are dealt with later in Section 6.0.

For "Time Until PFD Donned or Removed" (see variable 31 in Appendix VI-A), over two-thirds (68 percent) of the cases were not applicable since the victim did not use a PFD. Another 28 percent were coded unknown (many of these were unknown

for "PFD Availability and Use"). Thus the known and useful data come from only four percent of the ARM sample. The sample size is too small to allow any conclusions to be drawn.

Approximately 80 percent of the ARM victims were on boats with a sufficient number of PFDs aboard. About six percent were on boats that were known to not have a sufficient number of PFDs, while for 14 percent of the victims, this information was unknown. The probability of recovery was 0.939 for those with sufficient PFDs, 0.708 for those without, and 0.926 for the unknowns. Obviously, those with sufficient PFDs aboard had a much better chance for survival than those without.

For 78.5 percent of the ARM victims, the type of PFD (see variable 33 in Appendix VI-A) was either unknown or not applicable (no PFD). A total of 8.4 fatalities were using nonapproved devices. However, no other victims were using nonapproved devices so the sample size is extremely small. The percentage of known users of each specific type of PFD was less than one percent, although over 3,500 people were projected to have used a Coast Guard-approved PFD of unknown type.

In the entire ARM sample, only 13 people are projected to have experienced a PFD malfunction, and nine of them survived. For the known PFD users in ARM, the reliability of the PFDs was over 99.7 percent (assuming no malfunction unless it was mentioned in the boating accident report). Similarly, only 55 of the projected 19,814 ARM victims were known to have used a PFD improperly (0.3 percent), and 28 of those were recoveries, while 27 died.

The final seven PFD variables included the number of PFDs on board of each type. These variables were known for less than two percent of the victims coded in ARM. (They were not coded for Phase I data - 32 percent of the ARM data.) Thus, the results on these variables are known for very small sample sizes, and are not presented.

Several variables were included in ARM which pertain primarily to the people involved in the accidents. Table VI-10 lists the number of victims in ARM from boats with varying numbers of people on board, and their corresponding probabilities of recovery. In general, there is a trend in the table for the probability of recovery to increase with more people on board, and the probability of

TABLE VI-10. PEOPLE ON BOARD

NUMBER OF PEOPLE ON BOARD	NUMBER OF VICTIMS IN ARM	PROBABILITY OF RECOVERY
1	724	0.747
2	3,696	0.853
3	4,036	0.901
4	4,363	0.955
5	1,863	0.969
6	1,680	0.968
7	1,679	0.991
8 thru 12	1,281	0.987
Unknown	492	0.944

recovery is relatively low for one or two people on board. The recovery data are related to boat size, boat type, activity, and other variables that are highly correlated with number of people on board. Correlations and similar phenomena in the data are discussed in greater detail in Section 6.0.

For "Victim's Sex", approximately 55 percent of the ARM victims were males, while 15 percent were females and 30 percent were of unknown sex. Considering only the known data, approximately four out of five victims are males. The probability of recovery for males (0.881) was less than that for females (0.939), while the probability of recovery for victims of unknown sex was very high (0.998).

With respect to age, 49 percent of the ARM victims were adults, eight percent were teenagers, three percent were children, and 40 percent were of unknown age. The probabilities of recovery were all relatively low, except for the unknowns: adults - 0.878, teenagers - 0.902, children - 0.842, unknowns - 0.993.

Poor health or heart trouble was known to have been a factor for only 33 people (all fatalities) of the 19,814 in ARM (0.1 percent). (See variable 27 in Appendix VI-A.)

Alcohol information was coded only for part of the Phase II data. For the data that were coded, approximately two percent of the victims were known to have been drinking, or drinking was suspected. The data were unknown for many cases, and not coded for many others.

Six of the ARM variables pertain specifically to the victim's boat. Table VI-11 shows the distribution of the ARM victims by the lengths of thier boats. Since victims are coded in ARM rather than boats, the percentages carry little meaning. For longer boats, more people are on board, so the percentages for those boat lengths are artificially large when compared to similar data tabulated for boats rather than victims. The probabilities of recovery by boat length show a clear tendency toward a higher chance of survival for larger boats. The unknowns on this variable have a relatively low probability of recovery (0.887). This may be due to accidents where few people were involved with a high percentage of fatalities so that no one survived to describe the vessel.

TABLE VI-11. ARM VICTIMS BY BOAT LENGTH

BOAT LENGTH (TO NEAREST FOOT)	NUMBER OF VICTIMS	PROBABILITY OF RECOVERY
10 ft or less (3.0 m)	356	0.597
11 - 15 ft (3.4 - 4.6 m)	4,055	0.827
16 - 17 ft (4.9 - 5.2 m)	3,893	0.928
18 - 19 ft (5.5 - 5.8 m)	3,081	0.965
20 - 22 ft (6.1 - 6.7 m)	1,555	0.967
23 - 25 ft (6.0 - 7.6 m)	2,137	0.978
26 - 35 ft (7.9 - 10.7 m)	2,520	0.977
36 - 45 ft (11.0 - 13.7 m)	1,046	0.989
46 ft and over (14 m)	357	0.995
Unknown	814	0.887

Table VI-12 presents the ARM data broken down by boat type. Boat type was known for all ARM victims except one. The table shows that the probability of recovery is relatively high for victims on powerboats, cabin cruisers, houseboats, and sailboats. These boat types account for over 93 percent of the victims in ARM. The probabilities of recovery for canoes, kayaks, open manual boats, and "other" boats in ARM is relatively low. Boat type appears to have a significant bearing on the probability of recovery.

The ARM data contain very little information concerning level flotation. Only 41 (0.2%) of the ARM victims were projected to have been on board level flotation

TABLE VI-12. ARM VICTIMS BY BOAT TYPE

BOAT TYPE	NUMBER OF VICTIMS	PROBABILITY OF RECOVERY
Open Manual	374	0.604
Open Power	11,044	0.922
Cabin Cruiser/Houseboat	4,785	0.975
Sail & Auxiliary Sail	2,675	0.968
Canoe/Kayak	376	0.588
Other	560	0.777

boats. This small sample size prohibits drawing any direct inferences concerning the probability of recovery for level flotation boats as opposed to boats with basic flotation or no flotation.

The hull identification number for the boats in ARM was known for 11 percent of the victims for whom the information was coded. (This variable was not included in Phase I).

The data for the type of power was coded only during Phase II. These data are tabulated below (Table VI-13). The most striking feature of this table is the unusually low probability of recovery for manually powered vessels (0.583).

TABLE VI-13. ARM VICTIMS BY TYPE OF POWER

TYPE OF POWER	NUMBER OF VICTIMS	PROBABILITY OF RECOVERY
Outboard	4,391	0.914
Inboard	2,462	0.977
Inboard/Outdrive	2,346	0.982
Sail & Auxiliary Sail	2,167	0.973
Jet Drive	308	0.993
Manual	647	0.583
Unknown	486	0.994
Not Coded	7,007	0.902

There are several variables in ARM which relate to PFDs, the people, the boat, and the environment, which might best be called accident variables. These variables code particular aspects of the accident which may be relevant to each victim's eventual outcome (recovery or death).

All accident types are well represented in ARM. Accident type was known for all ARM victims. The data are compiled in Table VI-14. The probabilities of recovery for various accident types fall into distinct groups. For collisions, groundings, fires, and explosions, the probability of recovery is very high (0.98+). For struck by the boat or prop and "other", the probability of recovery is somewhat low (0.88+). The probabilities of recovery for falls overboard (0.457) and capsizings/swampings (0.754) are very low.

TABLE VI-14. ARM VICTIMS BY ACCIDENT TYPE

ACCIDENT TYPE	NUMBER OF VICTIMS	PROBABILITY OF RECOVERY
Collisions/Groundings	13,452	0.985
Capsizings/Swampings	3,359	0.754
Fire/Explosions	1,410	0.992
Falls Overboard	643	0.457
Struck by Boat or Prop	128	0.884
Other	822	0.887

Most of the ARM accident victims were on lakes/swamps (40%), rivers/creeks (28%), or coastal waters (22%), with the remaining victims (10%) on ocean or Great Lakes' waters. The probabilities of recovery for various bodies of water did not vary much, ranging from 0.873 (Great Lakes) to 0.959 (coastal waters).

Water conditions (see variable 39 in Appendix VI-A) were known for 97 percent of the ARM victims (calm = 51%, choppy/rough = 39%, swift current = 7%). The probabilities of recovery were low for swift current (0.805), average for calm and choppy/rough (0.938 and 0.922, respectively), and very high for the unknowns (0.996).

By contrast, water temperature was known for only 41 percent of the ARM victims. Water temperatures ranged from 30°F (-1.1°C) to 85°F (29.4°C). These data are grouped in Table VI-15 to show changes in the probability of recovery across water temperature ranges. Although there are many unknowns, there is a general trend in this table toward higher probabilities of recovery in warmer water temperatures.

TABLE VI-15. ARM VICTIMS BY WATER TEMPERATURE

WATER TEMPERATURE	NUMBER OF VICTIMS	PROBABILITY OF RECOVERY
30 - 44°F (-1.1 to 6.7°C)	660	0.796
45 - 59°F (7.2 to 15°C)	2,134	0.901
60 - 74°F (15.6 to 23.3°C)	4,079	0.939
75°F and Over (23.9°C)	1,260	0.937
Unknown	11,681	0.930

Almost half of the ARM victims (49 percent) never entered the water. Understandably, the probability of recovery for those who never entered the water was very high (0.99). An additional 31 percent of the ARM victims entered the water for an unknown length of time. The data concerning time in the water (see variable 38 in Appendix VI-A) came from the remaining 20 percent of the victims. For those who did enter the water and whose time in the water was known, nearly three-fourths (73 percent) are recovered or dead within 15 minutes of entering the water. A total of 83 percent of these victims are recovered or dead within one hour of entering the water. Thus, whatever recovery mechanisms there are, they appear to work quickly for many accident victims. For others, the recovery systems need to act very soon after they enter the water, for there are many fatalities in the first hour (indeed, in the first 15 minutes!). <u>Longevity</u> of the rescue apparatus (a PFD, for example) does not appear to be as serious a problem as the <u>availability</u> of one, since only about one percent of the ARM victim outcomes are still in question after five hours in the water, but 83 percent are decided within the first hour.

For the victims in ARM, entering the water had a significant impact on their chances for survival. For <u>adults</u>, the probability of recovery for those who

never entered the water was 0.98; for those whose time in the water was unknown, the probability fell to 0.82, and for those with known time in the water, it was 0.78.

For time in or with the boat (see variable 29 in Appendix VI-A), over 84 percent of the data was unknown, and the known data was spread uniformly over all of the possible codes, so that no extractions from the data could be made.

Pleasure cruising, water skiing, racing, stopped/drifting, "other", and unknown accounted for the activities of 89 percent of the ARM victims (see variable 18 in Appendix VI-A). All had similar probabilities of recovery, ranging from 0.931 (pleasure cruising) to 0.988 (racing). The activities of fishing, hunting, skin diving, and swimming accounted for the activities of the remaining 11 percent of the ARM victims. These activities led to a combined probability of recovery of 0.78. Based upon the ARM data, these appear to be activities leading to greater risk of death in the event of an accident.

The distance to shore or another vessel was unknown for half of the ARM victims. A direct inverse relationship between distance to shore or another vessel and the probability of recovery is shown in the data in Table VI-16. For over 88 percent of the known data, the distance to shore or another vessel was 300 yards or less, indicating that for the bulk of the accident victims, a rescue system would not have to operate over great distances in order to be effective in providing access to land or another vessel (i.e., a source of rescue). There is a clear trend in Table VI-16 toward a higher probability of recovery when the accident victim is closer to a potential source of rescue.

TABLE VI-16. ARM VICTIMS BY DISTANCE TO SHORE OR ANOTHER VESSEL

DISTANCE TO SHORE OR ANOTHER VESSEL	NUMBER OF VICTIMS	PROBABILITY OF RECOVERY
0 - 5 yards (0 - 4.6 m)	2,893	0.957
5 - 300 yards (4.6 - 274.5 m)	5,837	0.916
300 - 900 yards (0.3 - 0.8 km)	530	0.859
900 yards - 2 mi (0.8 - 3.2 km)	509	0.753
Greater than 2 mi (3.2 km)	142	0.700
Unknown	9,903	0.936

There is very little evidence in ARM that visual distress signals are used. Only 3.1 percent of the ARM victims used signalling devices, and these were effective (in gaining the attention of a rescuer) in 80 percent of the cases when used. The probability of recovery for those who used a signalling device was greater (0.954) than for those who did not (0.924).

Who were the rescuing agents? The assisting party was unknown in 35 percent of the cases, and there was no assisting party for 30 percent of the victims. Boaters from other boats or the victim's own boat accounted for the assistance provided for 24 percent of the victims. The remainder were assisted by the Coast Guard (3%), Coast Guard Auxiliary (0.1%), state or local officials (4.4%) or others (3.5%). The probabilities of recovery for all of these assisting parties were greater than 0.92, with the exceptions of "no one" (probability of recovery = 0.857) and "boater from same boat" (0.849).

For final boat configuration (see variable 24 in Appendix VI-A), the unknowns accounted for over 18 percent of the data. Over one-half of the victims were from boats which remained upright and not swamped. About four percent were from capsized or swamped boats which floated level fortuitously, while 16 percent of the victims were from nonlevel capsized or swamped boats,and 11 percent were from boats that sank. The probabilities of recovery were highest for categories corresponding to nonswamped boats and unknowns. A more detailed analysis of this variable can be found in the benefit estimations of Section 6.3.

The victim's condition (see variable 26 in Appendix VI-A) was known (or could be reliably assumed) for 99.6 percent of the ARM victims. Several comparisons can be made from these data. Known swimmers (13 percent of the victims) had a much higher probability of recovery (0.801) than known nonswimmers (1.5 percent of the victims with a probability of recovery of only 0.348). There are a projected 76 (0.4%) people per year who are unconscious upon having an accident, and their probability of recovery is less than a half (0.478). Thus, there are approximately 39 to 40 deaths involving victims who are made unconscious by the accident. An additional 1,087 (six percent) are seriously injured. Adequate emergency treatment is provided in five out of six (83 percent) of these cases. By far the majority of the cases in ARM (72 percent) are coded "conscious". These are cases where it was known that the victim was conscious and not seriously injured, but

swimming ability was not known. The probability of recovery for these victims was high (0.979).

The victim's behavior and circumstances is a complicated variable (see variable 28 in Appendix VI-A). This part of the ARM model is closer to the original decision tree versions of the model than any other part. Therefore, a single code from this variable can convey a lot of meaning. The data for this variable are presented in Table VI-17. The table is structured in order to reflect the relationships between the codes in the ARM decision tree for this variable. Over 70 percent of the ARM victims were in their boats immediately after their accidents (codes 31, 31, 2, 3, 1), and yet many (16.2 percent of the total) wound up separated from their boats. The extremely high probabilities of recovery for those victims who remained in their boats or re-entered them (codes 31, 1 and 4) indicate that providing a boat that can be re-entered, and educating the boater to do that, may lead to many more lives being saved. This problem is discussed in later paragraphs, including Section 6.3. Codes where the probability of recovery is very low include those who wind up in the water and 1) lose their grip when holding onto the boat (0.164), 2) are separated from the boat for an unknown reason (0.633), are forced to leave (0.534), or are trapped or entangled (0.458). Those who are in the water and voluntarily leave have a much higher probability of recovery than those who are forced to separate from the boat by being thrown out or falling out (0.842 to 0.534). Those who are forcibly separated from an "in boat" position fare much better than those who are forcibly separated from the boat in an "in water" position (code 3 - 0.943 to code 10 - 0.534). Similarly, a voluntary decision to leave from an "in boat" position (code 2) results in a higher probability of recovery (0.935) than for a voluntary decision to leave from an "in water" position (code 9 - 0.842). These data lead to the conclusion that the same behaviors from an "in the water" position lead to significantly lower probability of recovery than from an "in boat" position. Yet, re-entering the boat from the water (code 4) results in almost the same probability of recovery as those who never enter the water at all (codes 1 and 31). The code "99" was used for the few victims in ARM who ended up on a dock, or land, or in a tree as a result of their boating accidents.

TABLE VI-17. BEHAVIOR AND CIRCUMSTANCES FOR ARM VICTIMS

ARM CODE *1	MEANING	NUMBER OF VICTIMS	% OF TOTAL ARM VICTIMS	PROBABILITY OR RECOVERY
31.	In Boat (Otherwise Unknown)	1,396	7.0	0.998
21.	Separated from Boat (Otherwise Unknown)	218	1.1	0.942
2.	Swam for Shore	748	3.8	0.935
3.	Forced to Leave	2,230	11.3	0.943
1.	Remained in Boat	9,350	47.2	0.996
32.	In Water, Not Trapped (Otherwise Unknown)	479	2.4	0.982
22.	Remained in Water (Otherwise Unknown)	363	1.8	0.887
12.	Positioned on Boat (Otherwise Unknown)	0	0.0	- - -
5.	Remained on Boat	104	0.5	1.000
6.	Thrown or Washed Off	0	0.0	- - -
13.	Held onto Boat (Otherwise Unknown)	9	0.0	1.000
7.	Remained with Boat	685	3.5	0.964
8.	Lost Grip/Washed Away	170	0.9	0.164
14.	Separated from Boat	136	0.7	0.633
9.	Swam for Shore	1,080	5.5	0.842
10.	Forced to Leave	1,599	8.1	0.534
4.	Re-entered Boat	486	2.5	0.991
11.	Trapped or Entangled, in Water	103	0.5	0.458
99.	Victim Did Not Wind Up in the Water or the Boat	46	0.2	0.949
88.	Unknown	612	3.1	0.965
TOTAL		19,814	100.1 *2	0.925

*1 NOTE: The left-most codes have subclasses beneath them in the Behavior and Circumstances decision tree. The right-most codes are terminal nodes in that tree.

*2 NOTE: Slight round-off errors can accumulate over several estimates.

4.3 Summary of Basic ARM Results

- The ARM data were compared to Coast Guard data for several variables that were not included in the sampling plan. They compared favorably, in general, and showed no obvious nonrepresentative biases.
- Nearly half of the ARM data were sampled from 1975, the year they have been weighted to represent.
- The data for many PFD variables contained many unknowns, precluding significant detailed analysis.
- No evidence was found of significant PFD malfunctions or improper use of PFDs. However, the sample sizes for these variables were relatively small.
- Nearly three-fourths of all accident victims who enter the water are recovered or dead within 15 minutes (83% within one hour).
- Victims from boats with sufficient PFDs had a much greater probability of survival than those from boats lacking in PFDs.
- The probability of recovery increased with:
  - increasing people on board
  - increasing boat length
  - increasing water temperature
  - decreasing distance to shore or another vessel
- Victims from canoes, kayaks, open manual boats, and "other" boats had significantly lower chances for survival than victims from powerboats, cabin cruisers, houseboats and sailboats.
- Manually powered boats lead to an unusually low probability of recovery for accident victims.
- Victims from collisions, groundings, fires and explosions fared well, while victims in capsizings/swampings and falls overboard had much reduced chances for survival. Hit by the prop and "other" accident victims had intermediate probabilities of recovery (approximately 0.89).

- Hunting, fishing, skin diving and swimming lead to much lower probabilities of recovery than other activities.
- Over 1,100 victims per year were projected to be unconscious or seriously injured in an accident.

These basic presentations have pointed out the need for detailed analyses that examine several variables simultaneously. For example, do manually powered boats lead to lower probability of survival because of the kinds of accidents they are likely to be involved in, or because of the conditions in which they are used, or what? The next section (Section 5.0) addresses these kinds of questions using more complex data analyses, and provides the foundation for the benefit estimation techniques to follow in Section 6.0.

5.0 DATA ANALYSES

5.1 Methods

The methods used in performing the data analyses in this section (and much of Section 6.0) involve cross-tabulating variables and applying straightforward statistical techniques for evaluating contingency tables. As was mentioned in the previous discussion, the use of ARM data to answer basic questions about the recovery process is complicated by the fact that so many variables interact, and are partially dependent upon one another.

For example, PFD wear is strongly associated with more severe conditions on other variables than PFD nonwear. Boaters often do not don PFDs until and unless they are in trouble. Thus, a comparison of PFD wear to nonwear, without taking the other variables into account, would be misleading. In conceptually changing an accident victim from a PFD nonwearer to a PFD wearer, one is also changing, in effect, many other variables. In order to make such comparisons meaningful, they must be made under circumstances that are comparable. Thus, the cross-tabulating of variables (allowing comparisons of PFD wear versus nonwear, for example, in rough water conditions and calm, as opposed to overall water conditions) is critical for analyses of ARM data.

The main point to be remembered in this discussion (and in 6.0) with regard to the methods employed is that the apparent effect of changing from one category to another on a given variable (say, from not wearing a PFD to wearing) in terms of the change in percentage recovered, may be biased by the other variables which interact with the given variable (such as behavior, boat type, etc. for PFD use). There are three major impacts of these biases on the ARM data analyses:

- Variables within ARM tend to correlate and interact with each other, particularly variables such as PFD usage.
- Methods are available for measuring the degrees of interrelationship (through the contingency coefficients and χ^2 values) based upon the weighted data.
- The implications of these interrelationships bear directly upon benefit estimation.

5.2 Results

Weighted ARM data for selected combinations of variables are presented below. Of course, there are many combinations of variables which could be used in sorting the ARM data. There are nearly 1,000 possible combinations using only two variables at a time. Not all of these are presented in this report. Those that are presented are most relevant to USCG programs, particularly those that are relevant to PFDs. The data reported below are projected frequencies and probabilities of recovery for the population of reported boating accidents.

The preceding pages (Section 4.0) have presented ARM recovery data sorts for all of the major variables coded in ARM. Some of the tables have indicated that there are variables that interact with each other, or are highly correlated. These correlations or interactions can lead to counterintuitive results in terms of the probabilities of recovery. One important aspect to this problem is that it means that every benefit estimation problem, or evaluation of a set of conditions, must include an analysis of other variables than those of direct interest in order to determine interrelationships that may bias the results. Some of these biases are shown in the tables that follow.

Tables VI-18 and VI-19 show the ARM fatalities and recoveries for a cross-tabulation of accident type and boat type. These data are shown as verification of the weighting process. Comparisons of Table VI-18 with Table VI-3 and Table VI-19 with Table VI-4 reveal that the ARM data, when weighted accurately, match the Coast Guard data that they are intended to represent. The apparent exceptions to this statement are those blocked cells under falls overboard and "other" accident types where the projected ARM victims do not match the Coast Guard data reported earlier. These cells were the ones where the appropriate Coast Guard data were not available. The data from Table VI-4 in those cells were used to generate the weights (using all people on board minus fatalities - see Section 3.1, page VI-19), but the weights were not applied to all people on board who survived in those accidents, only to the actual recoveries (those actually at risk who survived). Thus, in those cells, the numbers from Table VI-4 represent upper bounds for the corresponding cells in Table VI-19, and should not necessarily be matched by Table VI-19. There are no estimates available for what these numbers should be. Thus, there is verification of the weighting program in Tables VI-18 and VI-19; i.e., the ARM data are weighted to match the appropriate Coast Guard data.

TABLE VI-18. ARM FATALITIES: BOAT TYPE BY ACCIDENT TYPE

BOAT TYPE \ ACCIDENT TYPE	COLLISIONS/ GROUNDINGS	CAPSIZINGS/ SWAMPINGS	FIRES/ EXPLOSIONS	FALLS OVERBOARD	HIT BY BOAT OR PROP	OTHER
Open Manual	3.44	103.74	0.00	32.36	0.00	8.55
Open Power	142.72	420.00	7.40	232.74	13.58	41.70
Cabin Cruiser/ Houseboat	19.52	40.95	4.13	37.20	0.00	16.31
Sail & Auxiliary Sail	5.67	42.70	0.13	21.66	0.00	15.45
Canoe/Kayak	12.61	136.51	0.00	5.77	0.00	0.00
Other	11.55	80.40	0.00	19.80	1.17	10.96

NOTE: 1488.72 total fatalities.

TABLE VI-19. ARM RECOVERIES: BOAT TYPE BY ACCIDENT TYPE

BOAT TYPE \ ACCIDENT TYPE	COLLISIONS/ GROUNDINGS	CAPSIZINGS/ SWAMPINGS	FIRES/ EXPLOSIONS	FALLS OVERBOARD	HIT BY BOAT OR PROP	OTHER
Open Manual	104.40	106.40	0.00	14.95	0.00	0.00
Open Power	7107.90	1561.68	684.98	239.40	105.92	484.62
Cabin Cruiser/ Houseboat	3510.36	416.64	639.08	18.87	0.00	79.83
Sail & Auxiliary Sail	2254.77	164.16	25.56	11.68	0.00	131.95
Canoe/Kayak	85.15	135.98	0.00	0.00	0.00	0.00
Other	187.88	148.72	48.92	8.80	6.83	31.68

NOTE: 18317.83 total recoveries.

The reader will note that only 19,807 victims are accounted for in Tables VI-18 and VI-19, out of the 19,814 total victims in ARM. The remaining seven victims were unknown on outcome (recovery/fatality) and are not tabulated. The cells where zeros occur in Tables VI-18 and VI-19, and nonzero entries are found in Tables VI-3 and VI-4, are those where no victims could be found in the ARM data. Thus, no weight could be large enough to cause a match with the Coast Guard data.

One of the many critical issues with respect to PFDs in this project was the extent of the need for self-actuation mechanisms for inflatable PFDs, if they were approved. One way to address this issue would be to ask how many adult accident victims might benefit from self-actuation of PFDs upon entering the water. These victims would include many of those that were unconscious, seriously injured, or drowned suddenly (in less than five minutes). The ARM variables of victim's condition, time in the water, age, PFD use, and outcome were categorized and crosstabulated in order to compute the desired quantities. A total of 779 victims would benefit from an automatic actuator on an inflatable PFD if they were to use one. This estimate includes some victims who may have been able to actuate a manual device, and therfore it should be considered a high estimate. Only 7.8 percent of these victims wore a PFD. The probability of recovery for these victims was approximately 0.50. Of the 779 incapacitated adults, about half survived (approximately 389) and approximately 40 of the recoveries were wearing PFDs. Thus, if inflatable PFDs without automatic actuation were substituted for fixed flotation PFDs that were worn, an additional 40 lives would be at risk beyond those who died. However, this would have to be weighed against the potential benefits from the inflatables in increased wear in order to properly evaluate their impact.

It should be noted that the estimate of approximately 40 lives being risked (which are not saved) due to inflatable PFDs that are not self-actuating is an upper bound. Even if inflatables were approved, it is very unlikely that all 40 would be wearing an inflatable. Also, some of the 40 may not be saved by their PFDs now. They are recoveries who were wearing PFDs, but they may have been rescued without the PFD being directly involved. If we estimate (assume) that only ten percent of these victims would be wearing inflatables, and half would be saved even with no PFD (by boaters in the immediate area, etc), then $40 \times 0.5 \times 0.1 = 2$ people would actually be at risk who were saved before.

These two would then be compared to the benefit from approving inflatables for the rest of the accident victims, considering increased wear rates, etc.

The analysis of the self-actuation issue for inflatables points out the complicated nature of most of the questions posed for ARM in this project. The data to support such estimates are often sketchy, and contain many unknowns. Performing the analyses in this section and the benefit estimates (Section 6.0) often requires insight into the data base, engineering judgment, and making assumptions about the unknown data, or the parameters of possible Coast Guard programs and their effects.

Cross-tabulations of time in water and water temperature were generated and used to estimate the magnitude of the hypothermia problem in recreational boating, and the role of PFDs in hypothermia cases (see Section 6.5). From these data it was established that between 117 and 795 victims per year are affected by hypothermia, and would benefit from PFDs that counteracted the effects of hypothermia. One such effect is to cause boating accident victims to lose consciousness and drown. The wear rate of PFDs for those who need the hypothermia protection is approximately 44 percent, which is very high. This figure seems counterintuitive until it is realized that these victims would not be likely to survive long enough to attain a hyopthermia condition without a PFD. The probability of recovery for PFD wearers suffering from hypothermia (0.85) was not significantly different from those who didn't wear a PFD (0.82). However, the sample size for known data was very small (approximately 92 percent of the data was unknown), so no reliable conclusions can be drawn concerning the role of PFDs in hypothermia situations, other than the fact that the wear rate appears to be high, so the potential exists for benefits from hypothermia protection in PFDs.

Elements from the analyses of incapacitated and hypothermic victims can be combined to provide information on the need for self-righting PFDs. All of the incapacitated and hypothermic victims need a PFD that passively orients the body to prevent drowning. Thus, there are a maximum of between 843 and 1,208 victims yearly who would need a PFD that turned an unconscious or incapacitated wearer. This represents approximately one-fifth of the adults who wind up in the water, and their current wear rate is between 11 percent and 21 percent. Of course, not all of the incapacitated victims would require a turning moment, so these estimates represent <u>upper bounds</u>. Also, many of these victims survive currently. Although a turning moment for PFDs might help them, it cannot be said that this would "save" them since many are recovered without any PFD.

What is the rate of PFD wear, holding, and donning for adults who enter the water? This is the kind of question that might require an answer as input to the Life Saving Index. The data for time in the water, PFD use, and age were cross-tabulated to provide information relative to this issue. Age was unknown for nearly 8,000 victims, time in the water was unknown for another 2,600, and PFD use was unknown for an additional 1,800. Therefore the rates that were determined are based upon the data from less than 38 percent of the ARM sample (the known data on this issue). The wear rate for PFDs for adults in the water is approximately 11 percent, the holding rate is four percent, and the donning rate is 11 percent. If the unknowns for time in water are included (since "not applicable" meant the victim never entered the water, "unknown" could mean "unknown if he entered the water" or "he did enter the water, duration unknown"), then the wear rate is 13 percent, the holding rate is three percent, and the donning rate is seven percent.

PFD use is crossed with these three variables in succeeding pages in order to demonstrate the interactive nature of analytical problems of the type addressed by ARM. Table VI-20 presents the data for PFD use crossed with water conditions for adult victims. Each cell in the table has two entries: the number of victims in the cell, and the probability of recovery for the cell (in parentheses). Some water conditions and PFD use codes were combined to provide adequate sample sizes in every cell.

TABLE VI-20. ARM ADULTS: PFD USE BY WATER CONDITIONS

PFD USE	WATER CONDITIONS	
	CALM NUMBER OF VICTIMS (PROBABILITY OF RECOVERY)	CHOPPY/ROUGH/SWIFT CURRENT NUMBER OF VICTIMS (PROBABILITY OF RECOVERY)
PFD Worn	359 (0.95)	518 (0.87)
PFD Held or Donned	247 (0.93)	345 (0.87)
No PFD	3,267 (0.88)	3,101 (0.83)

NOTE: There are 1,841 unknowns for this table.

There is a trend in each water condition category for higher probabilities of recovery if PFDs are used. This effect is more pronounced in the calm data. The chi-square statistic of association for these data is very significant (χ^2 = 48.1, degrees of freedom = 2, $p < 0.001$). The proportions of PFD users (wearers, holders, donners) are higher in rough water than would be expected by chance. Thus, if one were to look at probabilities of recovery for PFD use alone, the data would be biased by the fact that PFD users tend to be in rougher water conditions than non-users.

Occasionally, statistically significant results from small sample sizes are derivable from ARM. Data for victims who were trapped under a boat or entangled were tabulated against PFD wear. Several categories of PFD use were combined into "None or Not Worn" to produce an adequate sample size in all cells for a chi-square computation. The data in Table VI-21 show that PFD wearers are more likely to have been trapped or entangled than nonwearers (corrected χ^2 = 29.2, degrees of freedom = 1, $p < 0.001$); i.e., PFD wearers are in more adverse conditions than nonwearers. The data tabulated are the total number of victims in each cell and the probability of recovery (in parentheses) for each cell. All recoveries in "trapped or entangled" were wearing PFDs.

TABLE VI-21. ARM ADULTS: PFD USE BY CIRCUMSTANCES

PFD USE	CIRCUMSTANCE	
	NOT TRAPPED OR ENTANGLED	TRAPPED OR ENTANGLED
PFD Worn	862 (0.90)	14 (0.84)
No PFD or Not Worn	6,965 (0.86)	19 (0.00)

NOTE: There are 1,791 unknowns for this table.

PFD use data were also broken down for swimmers and nonswimmers. Although known swimmers had a much higher probability of recovery than known nonswimmers (0.78 to 0.31), the groups were indistinguishable when wearing PFDs (0.86 for swimmers wearing PFDs and 0.89 for nonswimmers wearing PFDs).

An enlarged discussion of the influences of other variables (biases) on the probability of recovery for PFD use can be found in Section 6.2.

Information concerning other aspects of the role or influence of PFDs in accidents can be gained from ARM as well. For example, is PFD use related to the source of assistance? One might predict that without a PFD, an accident victim would need to be rescued from his own craft, since he might not survive long enough to be rescued by someone else. A somewhat different trend was observed in the data. Table VI-22 shows the number of people and probability of recovery (in parentheses) for each combination of PFD use and whether or not the assisting party was from the same vessel as the victim. The data indicated that it is very unlikely that a person holding or donning a PFD will be assisted by a boater from the same boat, while it is unusually likely that a PFD wearer will gain assistance from his own boat (χ^2 = 174, degrees of freedom = 2, p << 0.001).

TABLE VI-22. ARM ADULTS: PFD USE BY ASSISTING PARTY

PFD USE	ASSISTING PARTY	
	ANOTHER BOATER FROM THE SAME BOAT	ALL OTHER TYPES OF ASSISTANCE
PFD Worn	190 (0.96)	561 (0.86)
PFD Held or Donned	12 (0.00)	552 (0.91)
No PFD	573 (0.71)	4,415 (0.84)

NOTE: There are 3,174 unknowns for this table.

Over one-fourth (25.3 percent) of those who wore PFDs were assisted by a party from their own boat, while only two percent of the PFD holders and donners, and only 11 percent of those without a PFD were assisted by parties from their own boats.

In Phase I of the PFD study, sudden drownings were identified as a major problem in boating safety (see Reference 1). The ARM data are tabled by PFD use in Table VI-23 for those victims who were not seriously injured and had a time in the water of less than five minutes. (This implies that the deaths in the table would be very likely to be sudden drownings.) The probability of recovery is much lower for those without a PFD <u>in the first five minutes</u>, indicating that PFD wear (instant accessibility) is very important in saving the lives that are lost in those minutes. However, those who wear PFDs are not completely immuse from sudden drowning.

TABLE VI-23. ARM VICTIMS: PFD USE FOR NONINJURED, IN THE WATER FIVE MINUTES OR LESS

OUTCOME	PFD USE		
	PFD WORN OR DONNED	HELD OR USED	NO PFD
Number of Recoveries	196	98	968
Number of Fatalities	14	8	267
Probability of Recovery	0.93	0.92	0.78

NOTE: There are approximately 775 unknowns for this table.

5.3 Summary

Many more results and cross-tabulations of the type presented here are described in the benefit estimation problems in the next section (Section 6.0). What has been shown here is:

- The weighted ARM data match the desired goal of the sampling plan and weighting program.
- The recovery process, in general, is very complex, and depends upon the specific interactions of the many variables describing the boat, the people, the environment, and the accident.
- Specifically, many variables correlate with PFD use, such as water conditions, victim's circumstances, etc, and most are related in such a way that PFD wearers experience the most severe condiitons on related variables more often than nonwearers. Obviously, the boater who uses a PFD may do so in response to threatening circumstances, and this fact is captured in the multiple variable analyses that have been done in this section and will be done in the next section.
- The relative importance of PFD properties can be demonstrated using carefully constructed sortings of the ARM data. Such properties might include: automatic self-actuation for inflatables, the turning of an unconscious wearer, the trade-off of wear (be sure he has it on in the first few minutes) with other characteristics (the need for hypothermia protection), etc.

- The need for detailed multiple-factor analysis of these complex problems, reflecting good engineering judgment, precise problem definition, and intimate knowledge of the ARM data base.

The last point launches the discussion of the benefit estimations in Section 6.0. Ample evidence has been provided of the complex interactive nature of the recovery/fatality process. Approaching these issues by breaking down each problem into multiple factors has been shown to be fruitful in indicating important relationships in the data. The "multistate approach" to benefit estimates described in 6.0 is an outgrowth of the realizations witnessed on the preceding pages.

6.0 ARM BENEFIT ESTIMATION: METHODS AND EXAMPLES*

The Accident Recovery Model is actually a data base containing data on numerous variables related to the circumstances of boating accident victims. It provides a good source of information for studies on the seriousness of these circumstances. In particular, it can be used in deriving estimates of the numbers of lives which could potentially be saved if the Coast Guard were to implement a new or revised safety program or regulation.

If a number of programs or regulations are under consideration, ARM can be used in estimating the potential benefit of each, so that they may be compared. Such programs will be concerned with increasing victim survivability; that is, increasing the probability of a victim surviving. This probability is called a victim's "recovery probability."

To increase victim survivability a program or regulation would attempt to change the conditions present after accidents to more favorable conditions. For instance, a program might be designed to increase PFD use. We shall call a condition such as "used a PFD" a "state." Thus, safety programs or regulations are designed to transfer victims from less desirable states (ones with lower recovery probabilities), to more desirable states (ones with higher recovery probabilities). A program designed to increase PFD use would result in victims being transferred from the less desirable state, "PFD not used," to the more desirable state, "PFD used."

The benefits, in yearly number of lives saved, is calculated by mathematically transferring victims from the less desirable state to the more desirable state in ARM. The number of victims in the less desirable ARM state is reduced by reassigning a part of this number to the more desirable state.

To express the benefit in the form of an equation, a small amount of notation must be introduced. Let R_0 represent the less desirable state with a victim survival probability of p_0 and let R_1 represent the more desirable state with

* The work in this section was performed under the USCG Regulatory Effectiveness Methodology project (Contract No. DOT-CG-42333-A, Delivery Order No. DOT-CG-70528-A) and shall appear, in expanded form, in the forthcoming report on that project (Reference 2).

a victim survival probability of p_1.* The survival probabilities are calculated by dividing the number of survivors in each state by the number of victims (survivors plus fatalities) in that state. A simple diagram aids in the calculation:

R_0	$\frac{a}{b} = p_0$
R_1	$\frac{c}{d} = p_1$

In this diagram b and d represent the total numbers of victims in states R_0 and R_1, respectively, while a and c represent the numbers of survivors in these states.

If a certain fraction, r, of the (number of) victims in R_0 is reassigned to R_1, these victims will have the higher recovery probability of R_1. In effect, (rb) victims will have their recovery probabilities reassigned from p_0 to p_1. This yields a benefit B,

$$B = rb\ (p_1 - p_0).$$

By substituting $p_0 = \frac{a}{b}$ into this equation, the benefit may also be calculated as

$$B = r\ (bp_1 - a).$$

This benefit calculation appears to be simple and straightforward. Regrettably, there are a number of complications which cannot be ignored. Consider, for instance, PFD use. Boaters do not decide to use or not use PFDs in a vacuum. Activity, boat type and length, water conditions, etc., all influence the decision to use a PFD. In general, the more severe the conditions a boater or boating accident victim finds himself in, the more likely he is to use a PFD. Thus, it is entirely possible for some accident victims using PFDs to have lower survival probabilities than other victims not using PFDs, not because PFDs are detrimental to survival but because they tend to be used more when severe conditions are present.

* The R-states are those which the project or Regulation will affect.

It is important to take these interacting conditions into account. The process used to do this has been termed "multistate benefit analysis" and, as the following hypothetical example illustrates, failure to properly use multistate analysis can result in gross errors in benefit estimation.

Consider the following diagrams, one for relatively non-severe accident circumstances and one for severe accident circumstances. In each diagram hypothetical numbers of victims and survivors have been included. As can be seen, in each case PFD use is beneficial; that is, it has a higher recovery probability than non-use.

Non-Severe

R_0 (PFD Not Used)	$\frac{a_1}{b_1} = \frac{980}{1000} = 0.98 = p_{01}$
R_1 (PFD Used)	$\frac{c_1}{d_1} = \frac{99}{100} = 0.99 = p_{11}$

Severe

R_0 (PFD Not Used)	$\frac{a_2}{b_2} = \frac{200}{300} = 0.67 = p_{02}$
R_1 (PFD Used)	$\frac{c_2}{d_2} = \frac{250}{300} = 0.83 = p_{12}$

Suppose it is estimated that in both the severe and non-severe cases r = 20% of PFD non-users can be made PFD users. The benefits resulting would be

$$
\begin{aligned}
B &= B_1 + B_2 \\
&= rb_1 (p_{11} - p_{01}) + rb_2 (p_{12} - p_{02}) \\
&= (0.2)\ (1000)\ (0.99 - 0.98) + (0.2)\ (300)\ (0.83 - 0.67) \\
&= 2 + 9.6 \\
&\approx 12 \text{ lives saved annually.}
\end{aligned}
$$

Let us compare this result with the answer we get when victims are not separated according to severe and non-severe accident circumstances. Summing the victims and survivors in the two cases yields the following diagram:

R_0 (PFD Not Used)	$\frac{a}{b} = \frac{1180}{1300}$ $= 0.91$ $= p_0$
R (PFD Used)	$\frac{c}{d} = \frac{349}{400}$ $= 0.87$ $= p_1$

Note that in this table $p_0 > p_1$ so that PFD non-use appears to be preferable to PFD use. If we were to use this table to calculate the benefit of transferring 20% of the PFD non-use victims to PFD use, we would obtain the benefit

$$
\begin{aligned}
B &= rb\ (p_1 - p_0) \\
&= (0.2)\ (1300)\ (0.87 - 0.91) \\
&\approx -10 \text{ lives saved annually.}
\end{aligned}
$$

We thus see that if strongly interacting conditions, such as accident severity, are not taken into account, gross errors can be made in benefit estimation calculations.

In the following paragraphs we describe the multistate benefit analysis approach in greater detail.

6.1 Multistate Benefit Analysis

It is imperative that the reader realize that:

> THE NEED FOR MULTISTATE BENEFIT ANALYSIS IS NOT A RESULT OF ARM DATA SAMPLING BUT, RATHER, IS DUE TO THE INTRINSIC NATURE OF ACCIDENT SURVIVABILITY, WHICH DEPENDS ON SEVERAL INTERRELATED FACTORS.

To aid in multistate benefit analysis we combine the diagrams for the different interacting factors. For instance, the two diagrams in the above example would be combined as follows:

	C_1 (Non-Severe)	C_2 (Severe)
R_0 (PFD Not Used)	$\frac{a_1}{b_1} = \frac{980}{1000} = 0.98 = p_{01}$	$\frac{a_2}{b_2} = \frac{200}{300} = 0.67 = p_{02}$
R_1 (PFD Used)	$\frac{c_1}{d_1} = \frac{99}{100} = 0.99 = p_{11}$	$\frac{c_2}{d_2} = \frac{250}{300} = 0.83 = p_{12}$

The rows of such a diagram will represent the states that a regulation or program is designed to transfer victims between, while the columns will represent the "Correlated" conditions C_1, C_2, etc., which interact with these states. We shall also call these correlated conditions "states" and shall call the intersection of R- and C-states "substates."*

---

* In Reference 3 the R- and C-states were called S- and T-states, respectively.

Thus, in the diagram R_1C_2 is the substate "PFD Used-Severe Conditions." Benefit calculations may then be performed column-by-column (C-state by C-state) and the results summed to give the total benefit. This is the first method used in the above example, which resulted in an annual benefit of twelve lives saved.

The question now arises as to how one determines which C-states to use in miltistate benefit analysis. The theoretical ideal would be to include all factors and combinations of factors which interact with the R-states. This would be equivalent to using a regression approach, using as regressors dummy variables representing all possible interactions of other factors with these states. Unfortunately, in most instances this approach would result in an unmanagably large number of C-states. Furthermore, for most of these states, there would be insufficient data in ARM and possibly even in the entire accident population. It is, therefore, necessary to follow some heuristic procedure in order to make a proper selection of a limited number of C-states. We first suggest some selection criteria and then present benefit estimation examples.

Because of the reasonably large ARM sample size, almost any choice of C-states will show some statistical interaction with the R-states. The selection of C-states should, therefore, have both a logical interaction with the R-states and a strong statistical interaction with the R-states. Two means of measuring this interaction are suggested, both of which are available as SPSS stastical options.

The R-states and C-states may be thought of as values of nominal variables R and C. A crosstabulation of these variables may be made, each cell of the cross tabulation containing the weighted ARM victim (survivor and fatality) frequency in a particular R_iC_j substate. An ordinary chi-square statistic may then be calculated for this table. Because this statistic is strongly dependent on sample size and it is calculated on weighted data, it must be adjusted for the weighting by multiplying it by the ratio $\frac{n}{N}$, where N is the total weighted sample size in the table and n is the total sample size in a corresponding table of unweighted victim frequencies. The upper tail probability (significance level) corresponding to the

adjusted chi-square value may then be found. The tables and charts in Appendix VII of Reference 4 are particularly recommended.*

It is suggested that crosstabulations for several selections of C-variables be made and the resulting upper tail chi-square probabilities compared. Those selections showing strong interactions (small probabilities) are good candidates for the final C-state selection.

Because even the unweighted sample size will usually be fairly large, several of the crosstabulations may yield extremely small probabilities. A second statistic, the Reduction in Uncertainty Coefficient, U, may then be useful as a supplement to the chi-square calculation or even as an alternative to it. U is an asymmetric statistic which measures the dependence of one variable on another. For our purposes, the U statistic which measures the dependency of R on C in weighted frequency crosstabulations is appropriate. A formula for this statistic may be found in Reference 5, p. 226 or Reference 6, p. 751. The value of U is independent of sample size and varies between 0 and 1, larger values indicating greater dependence.

In order to obtain credible benefit estimates, we must have accurate recovery probabilities for those substates R_iC_j that victims are to be transferred into. The C-variable selected must, therefore, not be one for which many of the weighted ARM victims in State R_i have an unknown C-state. Furthermore, if the unweighted victim frequency in a substate R_iC_j is small, the recovery probability in that state will be unreliable. In such a case, that C-state should be combined with another C-state if it is logically reasonable to do so. (It would not be logical, say, to combine boats under 10 feet with boats over 26 feet in length). Otherwise, victim frequencies in that C-state could be omitted from the benefit calculations. It should also be noted that if more than a small fraction of the weighted victims have an unknown R-state, all recovery probabilities may be unreliable and so benefit estimates may also be unreliable.

---

*Note that in some printings of this reference, the row and column headings in Table 1 of this appendix are reversed and must be interchanged.

A C-variable should not be selected if the transfer of victims between R-states will likely cause a transfer between C-states. For instance, if the R-variable represents a decision to remain or not remain with a boat, the C-variable should not be "time in or with boat." The difficulty associated with the choice of such a C-variable is that it can severely complicate the benefit estimation process. Also, one should note that C-states cannot be combined if different transfer rates are to be applied to them. Finally, one must realize that a failure to properly use the multistate method could result in an overestimation of benefits instead of an underestimation, as in the example. To see this, one may merely reverse the roles of R_0 and R_1 in the previous example.

6.2 Benefit Estimation for Increased PFD Use

In this example, benefits from increasing PFD use were calculated. The appropriate variable in ARM is Variable 30, "PFD Availability and Use." As a coding tree is used for this variable, it was possible to code partial information on PFD use and, in fact, this did occur to a significant extent. Consequently, it was decided to combine the victim frequencies for different variable values into three R-states: PFD Used, PFD Not Used, and PFD Use Unknown. Benefits were calculated for the transfer of victims from "PFD Not Used" to "PFD Used." These calculations were made under the assumption that the only change would be in PFD use. It was assumed that other factors, such as the mix of PFD types and their overall effectiveness, would remain unchanged. The "PFD Use Unknown" state was not used in the benefit calculations. This was justified on the grounds that in almost every instance, whether considered in an overall context or in a multistate context, the recovery probabilities in this state were higher than in the "PFD Used" state. The reason for this anomoly of higher recovery probabilities in the "PFD Use Unknown" state is uncertain. Perhaps less information is furnished in accident reports covering less severe accidents, so that this state represents less severe accidents with higher recovery probabilities.

6.2.1 Analysis

As described in the Technical Details section, the multistate analysis guidelines were used to select appropriate C-variables which interacted strongly with the "PFD Use" R-variable. The three "best" choices for a C-variable showed equally strong interactions with the "PFD Use" R-variable. These three variables were derived by combining the "Final Configuration of Boat" variable (24) with each of the variables "Boat Type" (17), "Activity" (18), and "Accident Type" (16).

No objective criteria could be found for selecting one of these variables as "best" and sample size limitations prevented combining three variables, so benefit estimates were calculated separately with each of these C-variables. Because the three sets of benefit estimates varied widely and there were no objective criteria for preferring one over another, means (maximum likelihood estimates) of these estimates were also calculated. Table VI-24 summarizes the results of these estimation calculations. The methods used in obtaining these estimates are described below.

Benefits due to current PFD use were calculated by estimating the number of lives which would be lost if no one used a PFD. This was done by transferring all PFD users in each C-state to the corresponding PFD non-use state, that is, by assigning PFD users in each C-state the recovery probability of non-users in that state. By then subtracting the current number of survivors using PFDs, the loss from non-use was obtained. This potential loss is, then, the benefit from current use. We illustrate these calculations with the calculation based on the C-variable "Final Boat Configuration X Boat Type." The recovery probabilities and victim frequencies are taken from Table VI-27.

Benefit due to current use:

$$
\begin{aligned}
&= -\,(\text{loss due to non-use}) \\
&= -\,[(0.927)\,(415.34) + (0.966)\,(166.71) + (0.959)\,(203.72) + (0.834)\,(386.68) \\
&\quad + (0.923)\,(472.67) + (0.856)\,(187.31) + (0.962)\,(261.86) + (0.946)\,(102.72) \\
&\quad - (0.938)\,(2197.01)] \\
&\approx 50 \text{ lives}
\end{aligned}
$$

Benefits resulting from maximum (100%) PFD use were obtained by first estimating the benefits resulting from increasing PFD use from its current state to 100% use. This was done by transferring all non-users in each C-state to the corresponding PFD use state, that is, by assigning PFD non-users in each C-state the recovery probability of users in that state. The total benefit from maximum PFD use was then obtained by adding to this incremental benefit the benefit from current use. Again, the C-variable "Final Boat Configuration X Boat Type" is used to illustrate the calculation.

TABLE VI-24. ANNUAL BENEFITS RESULTING FROM PFD USE

(Benefits, in lives saved, calculated from a zero use rate base.)

C-Variable	Benefit From Current Use	Benefit From Maximum (100%) Use
Final Boat Configuration X Boat Type	50	258
Final Boat Configuration X Activity	123	490
Final Boat Configuration X Accident Type	124	598
Averaged Values	99	449

Benefit due to maximum (100%) use:

= (Incremental benefit due to increasing use from current amount to 100% use) + (Benefit from current use)

= [(0.934)(3502.48) + (0.993)(1613.12) + (0.955)(1747.63) + (0.820)(1466.29) + (0.075)(344.54) + (0.910)(697.23) + (0.991)(268.09) + (1.00)(1838.51) - (0.925)(11478.89)] + 50

≈ 258 lives.

The averaged values in Table VI-24 were obtained by simply averaging the benefit estimates for the three different C-variables.

As described above the "PFD Use Unknown" state was not used in any benefit calculations. If most of the victims in this state were actually users, we would have larger benefit estimates, while if most were non-users we would have smaller estimates. It is impossible to determine where to place these individuals. One could obtain a range of benefit values by first considering all of them as users and then considering all of them as non-users, computing benefit estimates for both extremes. Of course, in this case the lower estimates would be negative. One might also distribute these unknown cases using a more complex method, such as distributing the recoveries between "PFD Used" and "PFD Not Used" in the same proportions as are the recoveries in these states and distributing the unknown fatalities in a analogous manner. We chose to use none of these methods as we have no way of determining a preference for one over another.

PFD use can be thought of as resulting from two factors. A certain "base" amount of PFD use results from individuals who regularly use PFDs in almost all circumstances. Additional PFD use results from individuals who use PFDs only in certain circumstances. The regular users of PFDs contribute a certain base PFD use rate, γ_0, under all circumstances. A reasonable choice of a value for γ_0 is the minimum of the C-state use rates. After eliminating instances in which there was clearly insufficient data, the minimum use rates for the three C-variables used in the benefit calculations were found to vary from 5.1% to 5.3% with an average of 5.2%. This average base rate was used as the base rate γ_0 in our calculations. It should also be noted that use rate calculations were based only on victims for whom PFD use or non-use was known.

Let γ_i denote the PFD use rate in a state C_i. Then the total number d_i of PFD users in state C_i can be expressed as:

$$\begin{aligned} d_i &= \gamma_i(b_i + d_i) \\ &= \underbrace{\gamma_0(b_i + d_i)}_{\text{"regular" users}} + \underbrace{\delta_i(1 - \gamma_0)(b_i + d_i)}_{\text{circumstance - induced users}} \end{aligned}$$

The quantity δ_i is that fraction of the $(1 - \gamma_0) = 94.8\%$ non-regular PFD users who use as a result of being in state C_i. δ_i may be thought of as a circumstance induced use rate. Note that $\gamma_i = \gamma_0 + \delta_i(1 - \gamma_0) = 0.052 + 0.948\ \delta_i$, at the current base use rate. It is reasonable to assume that a Coast Guard program or regulation designed to increase the base PFD use rate will not affect the circumstance - induced rates δ_i. In fact, it can be shown (see Reference 2) that the assumption that the δ_i values will remain constant is equivalent to the assumption that the same faction of non-users are transferred to user status in each state, i.e., that the transfer rates r_i are the same for all states C_i. These assumptions imply that the benefit B is a linear function of the base use rate γ_0.

Using the averaged benefit values in Table VI-24, we obtain the equation* for the annual benefit of PFD use as a function of base use rate γ_0:

$$B = 369.2\gamma_0 + 79.8^*$$

Figure VI-9 shows a graph of this function and illustrates current use benefits as well as an example of benefits derivable from a higher (50%) estimate. Note that 79.8 is the benefit from circumstance - induced use when the base use rate is 0. The reader is reminded that this figure is based on the assumption that factors other than PFD use, such as PFD effectiveness, remain unchanged.

Finally, it should be noted that a Coast Guard program might not affect only the base PFD use rate, but may also differentially affect the overall use rates and circumstance - induced use rates. To perform calculations involving varying use rate changes, the multistate method must be used, benefits being calculated C-state by C-state.

---

* This equation is derived by substituting into the general equation, $B = \alpha\gamma_0 + \beta$, the averaged benefit values in Table VI-24 along with the corresponding base use rates. Thus,

$$99 = \alpha(0.052) + \beta \quad \text{(current use)}$$
$$449 = \alpha(1.00) + \beta \quad \text{(100\% use).}$$

Solving these equations simultaneously, we obtain $\alpha = 369.2$, $\beta = 79.8$.

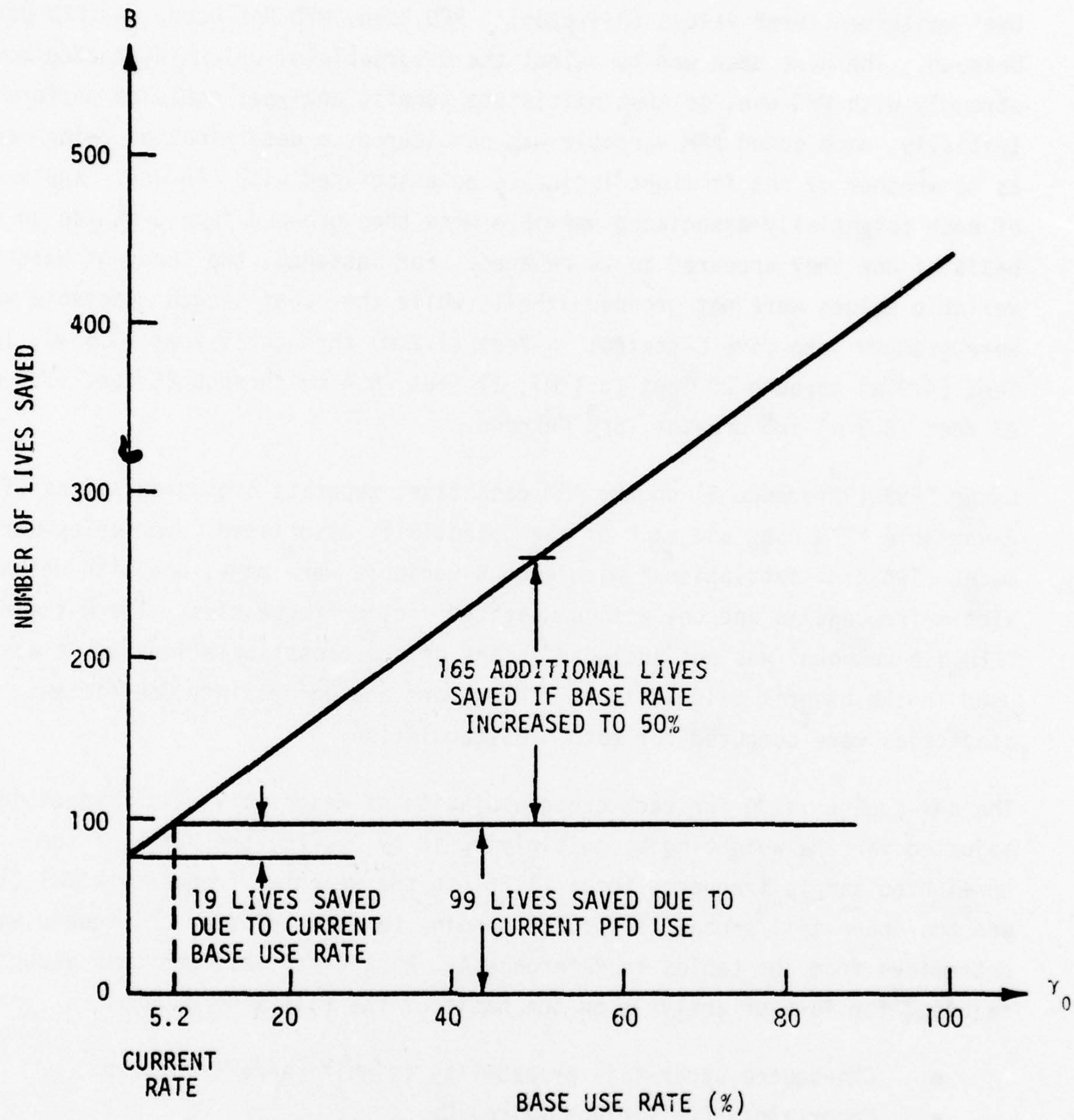


FIGURE VI-9. ANNUAL BENEFIT OF PFD USE AS A FUNCTION OF BASE RATE γ_0

6.2.2 Technical Details

The first step in the analysis has already been described; the R-variable "PFD Use" was given three values (R-states): PFD Used, PFD Not Used, and PFD Use Unknown. The next step was to select the C-variable(s) which interacted most strongly with PFD use, so that miltistate benefit analyses could be performed. Initially, each coded ARM variable was considered, a determination being made as to whether or not it might logically be associated with PFD use. The values of each potentially associated variable were then grouped into C-states on the basis of how they appeared to be related. For instance, the "Body of Water" variable values were not grouped at all, while the "Boat Length" variable values were grouped into five C-states: 4 feet (1.2 m) through 15 feet (4.6 m), 16 feet (4.9 m) through 20 feet (6.1 m), 21 feet (6.4 m) through 26 feet (7.9 m), 27 feet (8.2 m) and greater, and Unknown.

Using SPSS (Reference 5) on the ARM data base, separate crosstabulations of the R-variable "PFD Use" and each of the potentially associated C-variables were made. Two crosstabulations* with each C-variable were made, one with weighted victim frequencies and one with unweighted victim frequencies. The R-state "PFD Use Unknown" was not included in any of the crosstabulations as it was not used in the benefit calculations. Chi-square and Uncertainty Coefficient statistics were computed for each crosstabulation.

The chi-square value for each crosstabulation of weighted victim frequencies was adjusted for the weighting by multiplying it by 0.0778, the ratio of the unweighted sample frequency total (1126) to the weighted frequency total (14473), and the upper-tail probability corresponding to each adjusted chi-square was determined from the tables in Reference 4. Each C-variable was then accepted or rejected for further analysis on the basis of the following points:

- Chi-square upper-tail probability (significance level), p.
- Uncertainty Coefficient value, U.
- Fraction of weighted frequency total for which the C-state was unknown.
- The possibility that a change in a victim's R-state would result in a change in his C-state (C-state transferrence).

---

* Example crosstabulations of weighted data are shown in Appendix VI-C.

Table VI-25 lists the C-variables considered, and the acceptance decision for each. The variable "Behavior/Circumstances" was conditionally accepted because it, along with "Final Boat Configuration" showed the greatest interaction with "PFD Use." Of the remaining accepted C-variables, "Boat Type" showed the strongest interaction.

The next step involved the pairwise combining of the accepted C-variables to create new variables which would have even stronger interactions with "PFD Use." Examples of these variables are found in Table VI-26. As the new variables would have many more values (C-states), the sample (victim) frequences for these values would be smaller, resulting in less reliable recovery probabilities. Consequently, the values of each accepted C-variable were checked for low unweighted victim frequencies. In those instances where small frequencies were found, values were combined if it was logically acceptable to do so, or omitted if it was not.

Combining variables to form new ones and obtaining crosstabulations with the new variables require a rather large amount of SPSS coding and computer time. Therefore, only those variables were combined which, it was believed, would yield the greatest interactions. In particular, "Final Boat Configuration" was combined with each of the other accepted C-variables, and the conditionally accepted "Behavior/Circumstances" variable was combined with "Final Boat Configuration" and "Boat Type."

Weighted and unweighted victim frequency cross tabulation of "PFD Use" with each of the new variables were made. As before, adjusted chi-square statistics and Uncertainty Coefficients were obtained and on the basis of these, three of the new C-variables were found to have the strongest interactions with "PFD Use." Table VI-26 contains detailed information on these variables. As all three showed equally strong degrees of association with "PFD Use," each was used in calculating benefits resulting from increasing PFD use.

To calculate benefits, three-way crosstabulations were made with each of the selected C-variables. Weighted and unweighted frequency crosstabulations of "Outcome" by C-variable by "PFD Use" were obtained. These tables yielded the

TABLE VI-25. C-VARIABLES TESTED AGAINST PFD USE

12 - Boat Length	Rejected - p too large, U too small
13 - Number of Persons on Board	Rejected - p too large, U too small
16 - Accident Type	Accepted
17 - Boat Type	Accepted
18 - Activity	Accepted
19 - Body of Water	Rejected - p too large, U too small
20 - Distance to Shore/Vessel	Rejected - too many unknowns
22 - Victim's Sex	Rejected - too many unknowns, U too small
23 - Victim's Age	Rejected - too many unknowns, p too large
24 - Final Boat Configuration	Accepted
26 - Victim's Condition	Rejected - p too large
28 - Behavior/Circumstances	Conditionally accepted - possibility of C-state transferrence
37 - Water Temperature	Rejected - too many unknowns
38 - Time in Water	Rejected - too many unknowns
39 - Water Condition	Accepted
50 - Type of Power	Rejected - too many unknowns

Certain other variables were immediately rejected because there clearly was insufficient data for them to be considered.

TABLE VI-26. C-VARIABLES USED IN BENEFIT CALCULATIONS

Each variable is the result of combining two (modified) ARM variables, one of which is "Final Boat Configuration." The body of the chart gives the variable values.

New Variable		Final Boat Configuration: Upright and Unswamped	Swamped	Sunk	Unknown
Final Boat Configuration X Boat Type	Open Powerboat	1	4	7	10
	Cabin Motorboat or Houseboat	2	5	8	10
	Other known boat type	3	6	9	10
	Unknown boat type	10	10	10	10
Final Boat Configuration X Activity	Pleasure crusing	1	5	9	13
	Fishing or hunting	2	6	10	13
	Water skiing	3	7	11	13
	Other known activity	4	8	12	13
	Unknown activity	13	13	13	13
Final Boat Configuration X Accident Type	Collisions/Groundings	1	5	9	13
	Swampings/Capsizings/ Floodings/Sinkings	2	6	10	13
	Fires/Explosions	3	7	11	13
	Other known accident types	4	8	12	13
	Unknown accident type	13	13	13	13

recovery probabilities and victim frequencies needed for the benefit calculations. In a few instances (R_iC_j substates) unreliable recovery probabilities, due to small unweighted victim frequencies, were found in the "PFD Use" state and, as the involved C-states could not be logically combined with other C-states, they were omitted from the benefit calculations. Table VI-27 contains the recovery probabilities and victim frequencies used in the three multistate analyses.

TABLE VI-27. MULTISTATE ANALYSIS TABLES FOR PFD USE

Each multistate table gives the recovery probabilities and weighted victim frequencies used in the benefit analysis calculations. Also included, in the shaded areas of the tables, are quantities which were not used in the calculations, but which may be of interest. These quantities are not included in the overall values. See Table VI-26 for variable value definitions.

PFD USE	Final Boat Configuration X Boat Type										
	1	2	3	4	5	6	7	8	9	10	OVERALL
NOT USED	0.927 3502.48	0.966 1613.12	0.959 1747.63	0.834 1466.29	0.923 344.54	0.659 651.67	0.856 697.23	0.962 268.09	0.488 31.16	0.946 1838.51	0.925 11478.89
USED	0.934 415.34	0.993 166.71	0.955 203.72	0.820 386.68	0.975 472.67	0.465 45.01	0.919 187.31	0.991 261.86	0.567 69.26	1.000 102.72	0.938 2197.01
USE UNKNOWN	0.981 1684.23	0.987 355.65	0.996 315.12	0.840 314.44	0.974 198.30	0.618 184.89	0.994 360.07	0.994 215.59	0.394 13.26	0.986 1693.28	

TABLE VI-27. MULTISTATE ANALYSIS TABLES FOR PFD USE (continued)

PFD USE	Final Boat Configuration X Activity													
	1	2	3	4	5	6	7	8	9	10	11	12	13	OVERALL
NOT USED	0.942 4098.01	0.811 366.68	0.967 395.32	0.968 2033.22	0.838 1647.20	0.694 683.65	--- 0.00	0.877 131.65	0.894 592.76	0.741 177.98	100.000 70.86	0.820 97.04	0.947 1869.35	0.909 12089.86
USED	0.959 263.05	1.000 83.90	0.956 282.06	0.903 151.76	0.917 448.84	0.818 329.52	--- 0.00	0.933 126.00	0.937 363.09	0.866 80.91	--- 0.00	0.815 74.43	1.000 102.72	0.917 2311.28
USE UNKNOWN	0.986 1437.98	0.962 68.66	0.969 268.08	0.990 677.97	0.833 426.53	0.640 137.80	1.000 32.68	0.949 100.62	0.993 323.27	0.394 13.26	--- 0.00	1.000 234.38	0.986 1723.26	

TABLE VI-27. MULTISTATE ANALYSIS TABLES FOR PFD USE (concluded)

PFD USE	Final Boat Configuration X Accident Type													
	1	2	3	4	5	6	7	8	9	10	11	12	13	OVERALL
NOT USED	0.986 5718.87	--- 0.00	0.989 216.04	0.678 928.32	0.956 878.22	0.686 1340.64	0.979 202.71	0.292 40.93	0.949 414.38	0.741 388.70	0.977 193.40	--- 0.00	0.946 1838.51	0.910 11723.68
USED	0.988 414.52	--- 0.00	1.000 168.94	0.811 172.31	0.957 224.47	0.845 564.40	1.000 98.32	0.498 17.17	0.940 424.77	0.814 88.18	--- 0.00	0.000 6.48	1.000 102.72	0.919 2190.31
USE UNKNOWN	0.999 1806.02	--- 0.00	1.000 172.04	0.904 377.92	1.000 104.32	0.788 592.72	0.000 0.59	--- 0.00	0.993 461.90	0.937 127.02	--- 0.00	--- 0.00	0.986 1692.28	

6.3 Level Flotation Benefits

The Coast Guard has recently promulgated a regulation which essentially requires that all outboard powerboats under 20 ft (6.1 m) in length float in a level position if they become swamped or capsized. It was our original intention to obtain an estimate of the minimum potential benefit of this regulation. However, analyses of ARM-generated data showed that it would be impossible to arrive at such an estimate using the data currently in the ARM data base. Thus, estimates of an upper bound on the potential benefit of the level flotation regulation were obtained.

The estimate we obtained for a maximum upper bound on the potential benefit of the level flotation regulation, assuming full implementation was 255 lives saved annually. In the following pages we shall describe the method used in arriving at this estimate. Because much of this analysis follows the same pattern as did the benefit analysis for PFD use, our description will be less detailed.

As the regulation only affects outboard power boats under 20 ft (6.1 m) in length, our analyses were restricted to data covering such boats, with a slight modification. Boat length data in ARM was rounded to the nearest foot so that, for instance, boats of length 19 ft 7 in. (5.9 m) were coded as 20 ft (6.1 m). Consequently, it was necessary to base our analyses on ARM data for outboard powerboats less than or equal to 20 ft (6.1 m) in length. An adjustment also had to be made for victim weighting in ARM. Victim weights were based on the entire data base. However, "Type of Power" was only coded in the current year's coding effort. Therefore, as described later, the benefit bound values obtained using weighted ARM data had to be adjusted by multiplying by a suitable factor.

Since data on recovery probabilities for level flotation boats is not available, our initial analyses were performed to answer the question: Could victim recovery probabilities for sampled, levelly floating, swamped or capsized boats be used as realistic minimum estimates of recovery probabilities for the new level flotation boats? Multistate analyses indicated that they could not. In almost all instances it was found that victim recovery probabilities for levelly floating, swamped or capsized boats were actually less than recovery probabilities

for boats which were not floating level or were sunk! Boats complying with the new level flotation regulation will perform quite differently when swamped than do current boats which happen to float level when swamped. The current boats are not at all stable when swamped and are very likely to capsize. Boats satisfying the new regulation will be very stable when swamped and will be unlikely to capsize. The recovery probabilities for victims in these boats will, therefore, be significantly greater than those for current, levelly floating boats.

Because it was impossible to obtain credible, minimum recovery probabilities for accident victims in level flotation boats, it was decided that the best that could be achieved would be upper bound estimates for the benefits of the level flotation regulation. To obtain these estimates, recovery probabilities in accidents when the boat remained upright, level and unswamped were used. The use of these probabilities raised serious questions. The most important of these concerned the fact that most accidents in which boats remain upright, level and unswamped are essentially different in nature from those in which boats are swamped, capsized, or sunk. In fact, in the ARM sample used, only the "collisions/groundings" accident type was represented in both categories.

It thus was necessary to assume that recovery probabilities for different accident types could be combined. To partially offset errors caused by this assumption, it was decided to obtain a range of upper bound estimates for the level flotation benefit and use the maximum of this range.

One estimate was obtained by using the overall victim recovery probabilities and frequencies for all victims in the sample. These were as follows:

	Victims	Recovery Probability
Swamped, Capsized or Sunk Boats	818.23	0.775
Upright, Level, Unswamped Boats	1843.54	0.931

This yielded a sample benefit bound of 127 lives which, as described above, had to be adjusted to take into account the fact that "Type of Powering" was only coded for part of the ARM sample. This adjustment is described below.

Multistate analyses were also performed in a manner similar to that described for the PFD use example. Among the reasonable choices for variables, "Activity"

was found to show the strongest interaction with the "unswamped" vs. "swamped, etc." categorization. The relevant data is presented in Table VI-28. The (unadjusted) benefit bound found in this analysis was 93 lives. Note that, in this instance, multistate analysis yielded a smaller benefit value than was yielded by the overall recovery probabilities and victim frequencies.

A number of other multistate benefit analyses using lesser-interacting variables were also performed. Almost all yielded values close to one of the two primary values, 93 and 127, that we obtained. A multistate analysis in which two variables were combined to yield a third new C-variable was not performed due to the relatively small sample size of 270 unweighted victims. Also, victim frequencies in instances where the final boat configuration was unknown were not included in the benefit bound calculations.

As described earlier, "Type of Power" was only coded for a portion of the ARM data base. Therefore, an adjustment factor had to be applied to our bound estimates. Now, the victim frequency weighting in ARM was based on 1975 fatality statistics. CG-357 data indicates that 753 fatalities occurred in 1975 with outboard boats, while the ARM sample contains 375.28 such fatalities. An appropriate adjustment factor was, therefore,

$$\frac{753}{375.28} = 2.01$$

The unadjusted upper benefit bound values we obtained were 93 and 127 lives. The adjusted values are, therefore, 187 and 255 lives. As 255 is the maximum of these values, our estimate of a maximum, upper bound on the benefit of the level flotation regulation, assuming full implementation, is 255 lives saved annually.

TABLE VI-28. MULTISTATE ANALYSIS TABLE FOR LEVEL FLOTATION

This table gives the recovery probabilities and weighted victim frequencies used in one of the benefit bound calculations. Also included, in the shaded areas of the table, are quantities which were not used in the calculations, but which may be of interest. These quantities are <u>not</u> included in the overall values.

Final Boat Configuration	Activity							
	Pleasure Cruising	Fishing or Hunting	Water Skiing	Not Underway: Skin diving Or Swimming Or Unknown	Racing	Other (Docking, etc.)	Unknown	Overall
Swamped or Capsized Or Sunk	0.751 243.99	0.752 449.65	---- 0.00	---- 0.00	0.880 18.57	0.821 49.96	0.979 59.06	0.756 740.60
Upright, Not Swamped	0.937 1112.74	0.850 115.29	0.992 290.380	0.877 243.85	---- 0.00	0.894 81.28	---- 0.00	0.919 1553.16
Unknown	0.975 524.33	0.900 194.63	1.000 179.74	1.000 144.38	0.880 18.57	1.000 32.68	---- 0.00	

6.4 Benefits Resulting from a Decision to Stay with One's Boat

In many instances an accident victim can decide whether to stay with his boat or not. Would such a victim be better off staying with his boat rather than leaving it? To answer this question we employed multistate benefit analyses using ARM data. Our analyses indicate that for those accidents which cause a boater to immediately enter the water, a small number of additional lives might be lost if boaters who leave their boats would instead decide to stay. This result applies to the current mix of boats, which includes extremely few level flotation boats. There is evidence for believing that once large numbers of level flotation boats are in use a decision to stay with one's boat will be beneficial. This conclusion arises, not only from the benefit analysis performed in the previous section and from actual test evaluations, but also from a second benefit estimate derived in this section: About 44 additional lives could be saved if those victims who are in their boats after an accident and voluntarily decide to leave would, instead, remain.

Interesting results regarding the use of PFDs and a decision to remain or not remain with a boat were observed during the benefit analysis. For accident victims who initially are in the water it appears likely that PFD use or non-use is independent of the decision to remain or not remain with a boat. However, for victims who are initially in their boats after an accident, PFD use is very highly associated with the decision to remain or not remain with a boat. Such victims who were wearing or who donned a PFD were much more likely to leave their boats than other victims.

Turning to the details of the analysis, it was, as the introductory remarks suggest, separated into two parts. The "Victim's Behavior and Circumstances (Variable 28)" coding tree, was used to separate victims into two groups, those who were still in their boats immediately after the accident took place and those whom the accident caused to enter the water immediately. We shall first describe the analysis involving the latter victims.

Victims under code 32 in the tree were separate into three states:

i) Victims who remained or tried to remain with their boats (codes 4, 5, 6, 7, 8, 12, 13)

ii) Victims who voluntarily left their boats (code 9)

iii) All other victims.

The third group was not used in the analysis.

Each ARM variable which might logically be related to a decision to leave or remain with a boat was crosstabulated against the victim states (i) and (ii), above. Statistical analyses of those crosstabulations in which the "unknowns" were not too numerous indicated that "Boat Length" had the strongest interaction with a decision to leave or remain. A multistate benefit analysis using this variable indicated that about nine additional lives might be lost if all victims who voluntarily leave their boats would, instead, remain. The boat length code "unknown" was not included in this analysis because of the small sample size and consequent unreliable recovery probabilities associated with it. (Including unknowns would have resulted in an unreliable net benefit value of five victims being saved.) The benefit value(s) obtained are sufficiently close to zero that it is reasonable to say that encouraging boaters to stay with their boats under these conditions would have little net effect on lives saved, and might have a negative effect.

As part of this analysis, "PFD Use" was crosstabulated against the victim's decision to leave or remain with the boat. Considering "PFD Used" vs. "PFD Not Used," an upper-tail chi-square probability (significance level) of over 0.25 was obtained. Taking into account wear vs. holding vs. non-use increased the probability (significance level) to 0.55 and including "unknown" raised it further still, to over 0.70. Thus, it is quite likely that a decision to remain or not remain with a boat is independent (or is nearly independent) of PFD use for those victims who immediately enter the water at the time of an accident.*

Turning now to victims who were still in their boats immediately after an accident, we separated victims into three categories as before:

i) Victims who remained with their boats (code 1)

ii) Victims who voluntarily left their boats (code 2)

iii) All other victims.

The third group was not used in the analysis.

* Were these not independent or nearly independent, very small chi-square probabilities (significance levels) would almost certainly have been obtained.

The same ARM variables as before were crosstabulated with "Victim's Decision" and for these victims several variables were found to interact strongly with the decision to leave or remain with a boat. These variables included "PFD Use," "Accident Type," "Final Boat Configuration," "Boat Length" and, somewhat less strongly, "Boat Type." Multistate benefit analyses were performed with each of these variables. Calculated potential benefits for remaining with a boat ranged from 34 lives saved annually when "Boat Type" was used as a C-variable to 47 lives saved annually when "Boat Length" was used as a C-variable. The average value (weighting "Boat Type" less strongly) was 44 lives saved annually. It appears that, for boaters who do not initially enter the water the decision to stay with the boat is a good one, at least in a statistical sense. That is, the decision leads to an overall benefit for such boating victims taken as a group, but may not be beneficial or may even be harmful for some individual boaters.

Examining PFD use for boaters who did not initially enter the water, we found that there was an extremely strong interaction between PFD use and a decision to remain with the boat. Of those wearing or donning a PFD, 54% left their boats, while only 6% of the remaining victims for whom PFD use or non-use was known left their boats. The chi-square upper tail probability (significance level) for use vs. non-use against a decision to remain or leave was less than 10^{-15}. Taking into account wear vs. holding vs. non-use reduced this already infintesimal probability as did the inclusion of "Unknown PFD Use."

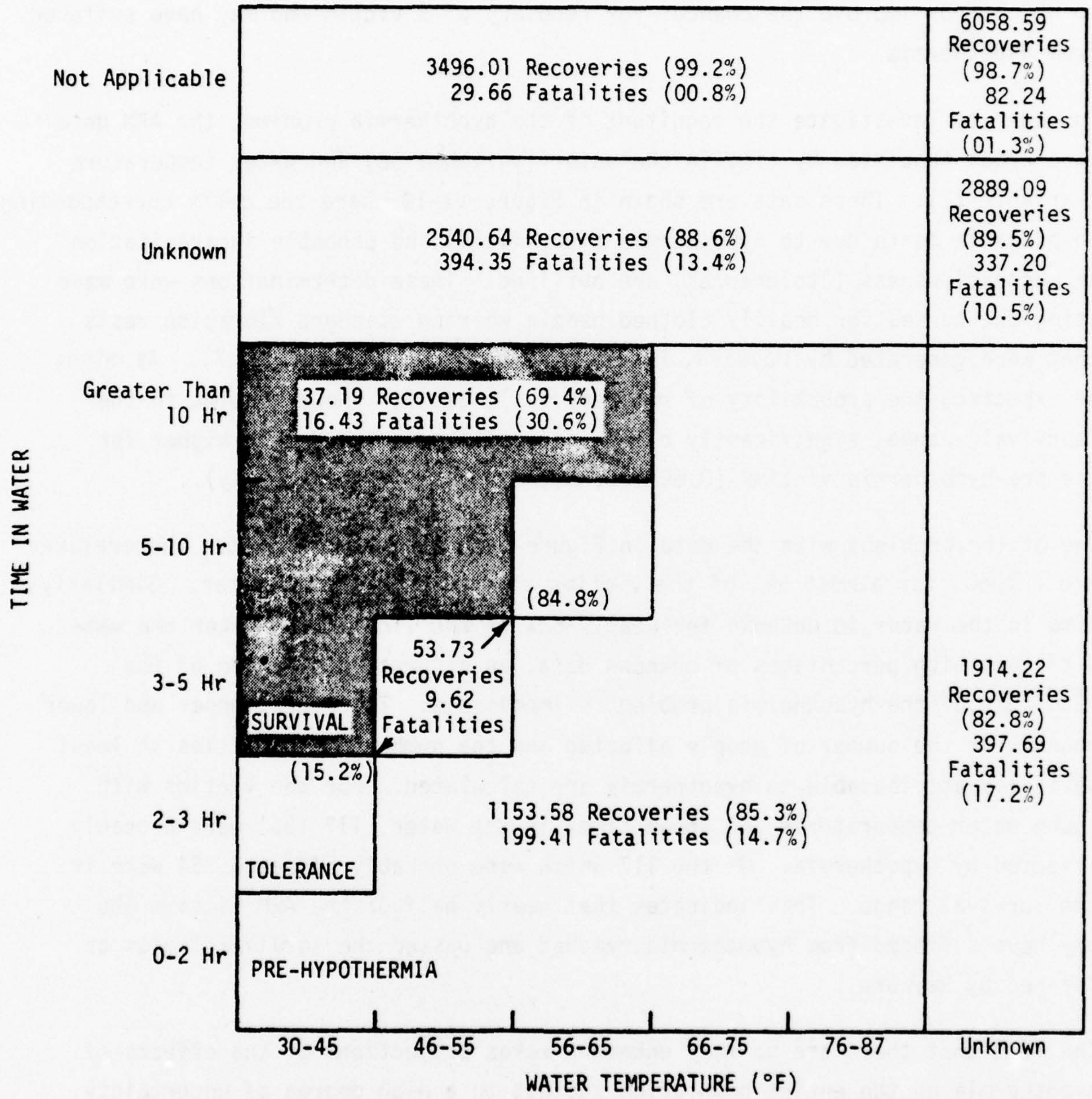
6.5 Benefit Estimation Problem: Hypothermia

The data in the accident recovery model were analyzed in order to determine the magnitude of the hypothermia problem in recreational boating and the extent to which PFDs improve the chances for recovery of a victim who may have suffered from hypothermia.

In order to investigate the magnitude of the hypothermia problem, the ARM data were cross-tabulated by time in the water (variable 38) and water temperature (variable 37). These data are shown in Figure VI-10 where the cells corresponding to probable death due to hypothermia ("survival") and probable incapacitation or unconsciousness ("tolerance") are outlined. These determinations were made using the curves for heavily clothed people wearing standard flotation vests that were generated by Hayward, Eckerson, and Collis (Reference 7). As might be expected, the probability of recovery is lowest for those victims in the "survival" range, significantly higher for "tolerance," and even higher for the pre-hypothermia victims (0.694, 0.848, and 0.853, respectively).

One of the problems with the data in Figure VI-10 is that the water temperatures are unknown for almost 56% of the victims that wind up in the water. Similarly, time in the water is unknown for nearly 62% of the victims who enter the water. With such high percentages of unknown data, an accurate projection of the magnitude of the hypothermia problem is impossible. Therefore, upper and lower bounds for the number of people affected and the number of fatalities at least partially attributable to hypothermia are calculated. For the victims with known water temperatures and known times in the water, 117 (8%) were probably affected by hypothermia. Of the 117 which were probably affected, 54 were in the survival range. This indicates that nearly half of the ARM victims who may have suffered from hypothermia reached and passed the survival limits as defined by Hayward.

The fact that there are so many unknowns makes projections of the effects of hypothermia on the entire population subject to a high degree of uncertainty. Certainly the 117 people effected and 26 deaths at least partially attributable to hypothermia in the figure represent a lower bound. If it is assumed that



Note: 19609.65 total victims = 18143.05 recoveries + 1466.6 fatalities in the figure

FIGURE VI-10. TIME IN THE WATER vs WATER TEMPERATURE FOR ARM VICTIMS

the unknowns for time in the water and water temperature are distributed in the same proportions as the knowns are for "survival," "tolerance," and "pre-hypothermia," then a total of approximately 795 people per year are affected by hypothermia, with 364 of them reaching the "survival" range. This would mean approximately 202 deaths per year are influenced by hypothermia. However, this assumption (that the unknowns are distributed in the same way that the knowns are) is not valid. The probability of recovery for the unknowns is greater (0.867) than for any of the known categories. This is probably due to two factors: 1) more details are usually given for fatalities, thus there are more fatalities in the known data, and 2) the unknowns are probably distributed more heavily toward the less severe conditions than the knowns (i.e., more "pre-hypothermia" victims). Thus, the 202 deaths and 795 total victims influenced by hypothermia represent upper bounds for the magnitude of the problem, while 26 deaths and 117 people effected represent the lower bounds.

Time in the water and water temperature were also cross-tabulated with PFD use to determine how PFD use might influence the probability of recovery in hypothermia cases. The addition of the PFD use variable to the analyses means that even more victims are unknown (add to the previous unknowns, those that are unknown for PFD use). However, some indications of the benefits of PFDs in cold water can be found. Table VI-29 shows the ARM data broken down by PFD use within each hypothermia category shown in Figure VI-10. PFD use was categorized according to whether the victim wore a PFD, used or held one, or had no PFD. While the data in Table VI-29 are sparse when compared to the unknowns, there is an indication that PFDs may be helpful in preventing deaths due to hypothermia. Note that in the "survival" range where death from hypothermia would be very likely according to Hayward's data, all of the recoveries were wearing PFDs, and all of those who were not wearing died.

In summary, between 26 and 202 boating deaths per year are influenced by hypothermia. In total, between 117 and 795 victims per year suffer from hypothermia to a significant degree, representing from 1-4% of the total population of boating accident victims. Although there are many unknowns, there is some indication that PFDs may prevent deaths due to hypothermia from prolonged exposure to cold water temperatures. This problem requires more data before any

confidence can be attached to conclusions concerning the magnitude of the hypothermia problem or the influence of PFDs on hypothermia.

TABLE VI-29. HYPOTHERMIA BY PFD USE

	No. of Recoveries	No. of Fatalities	Probability of Recovery
"Survival"			
PFD Worn	37.19	0.0	1.00
Held	0.0	0.0	-
None	0.0	8.03	0.0
"Tolerance"			
PFD Worn	17.91	9.62	0.65
Held	0.0	0.0	-
None	35.82	0.0	1.00
"Pre-Hypothermia"			
PFD Worn	290.17	29.20	0.91
Held	116.74	8.40	0.93
None	189.07	49.61	0.79
Unknowns	7901.55	1249.84	0.86

6.6 Benefits Resulting from Trade-Offs in PFD Characteristics

One of the basic considerations in the formulation of the Life Saving Index (see Section VII) was that PFDs could differ significantly in their characteristics and still maintain a specified level of performance in terms of the function of saving the life of a boating accident victim.

Since PFDs can (and do) vary on several parameters, including those used in computing the L.S.I. (wearability, reliability, and effectiveness), the issue of trade-offs among these parameters arises. If, in order to make a particular PFD more wearable, one must simultaneously reduce its effectiveness, what is the resulting impact on its life-saving capability? That kind of a question is the central issue in this benefit estimation problem.

A sensitivity analysis of the L.S.I. with respect to its various components is not appropriate to this section of the report. A brief sensitivity analysis of the L.S.I. can be found in Appendix VI-B. It will suffice to note here that the trade-offs of the parameters within the L.S.I. will alter the calculations for the particular PFD to be modified. The resulting L.S.I. for the modified PFD

may be lower, higher, or the same, as it was previously. The problem of estimating benefits from trade-offs in PFD parameters can be reduced, then, to estimating benefits from the changes in L.S.I. that results from the trade-offs.

Unfortunately, very little data was "known" in the ARM sample that pertain specifically to individual PFD types. Thus, instead of an analysis of the benefit from specific changes to a particular PFD, an analysis of the effects of changes in the average L.S.I. for all PFDs in use was implemented.

To begin with, it was assumed that an average L.S.I. of zero would result in no lives being saved by PFDs. There are several possible combinations of parameter values in the equation for the L.S.I. which could theoretically produce this result. For the purposes of this benefit estimation problem, the assumption need not correspond to any particular set of theoretical values.

Three methods of estimating the maximum possible benefits from PFDs were discussed previously (Section 6.2). No objective criteria could be found for selecting one estimate as "the best" of the three. Therefore, all three were used in this problem. The maximal benefits from PFDs is obtained when the average L.S.I. is 1.0. The average L.S.I. can attain the value of 1.0 (theoretically) through several combinations of parameter values in the equation for the L.S.I. However, with currently approved devices, the maximal L.S.I. is less than 1.0, since these devices have less than maximal reliability, wearability, accessibility, and effectiveness, on the average. For the purposes of this benefit estimation, it was assumed that the PFD with the highest measured index of wearability (0.58) was being worn by 58% of the ARM victims, and the remaining 42% of the ARM victims donned their PFDs during or after the accident. This assumption was made in order to correspond to the benefit estimation previously reported for 100% use of currently approved devices (Section 6.2).

As explained in Section VII of this report, the estimates of effectiveness that have been generated in the test tank (see Section VI) are upper bounds, since they were obtained in calm water with no clothing on the subjects. The empirical data, from ARM, indicate that 40% (or more) of the victims are in rough water, where the effectiveness would undoubtedly be lower than what was measured. To estimate the effectiveness of currently used devices from ARM the

equation for the L.S.I. must be used (see Section II).

$$LSI = [I_W \cdot E_W + I_{AC} \cdot P_D \cdot E_W + I_{AC} \cdot P_H \cdot E_H] \cdot R$$

where

I_W = The probability that the PFD is worn immediately prior to entering the water in an accident

I_{AC} = The probability that the PFD is accessible to a boater but not worn initially upon entering the water in an accident.

P_D = The probability that a victim dons the PFD in the water.

P_H = The probability that a victim holds or lies upon the PFD in the water.

E_W = The probability that the PFD maintains or turns the wearer in the water to a position with minimum required freeboard to the lower respiratory passage within a specified time limit.

E_H = The probability that the PFD provides a minimum required freeboard to the lower respiratory passage for a relaxed person holding or lying upon the device in the water.

R = The probability that the PFD will operate successfully for a specified period of time under specified conditions when used in the manner and for the purpose intended.

ARM can be used to estimate the percentages of people in the water who wear PFDs (I_W = 11%), don PFDs ($I_{AC} \cdot P_D$ = 13%), and hold them ($I_{AC} \cdot P_H$ = 4%). The average overall Life Saving Index in ARM would be approximately the number of adult recoveries from victims in the water known to be using PFDs divided by the number of adult victims in the water for whom PFD use was known. Thus,

$$\text{Average LSI in ARM} = \frac{\text{690 adult recoveries using PFDs}}{\text{5206 adults in water with PFD use known}} = 0.133.$$

It should be noted that there are over 4,000 adult victims for whom time in the water and/or PFD use were unknown.

Using the LSI equation, and the ARM parameter estimates, an estimate for the upper bound of PFD effectiveness in ARM can be derived, as shown:

Using $R \simeq 0.997$ (see Section 4.2)

$$0.133 = [0.11\, E_W + 0.13\, E_W + 0.04\, E_H]\, 0.997$$

$$0.133 = 0.24\, E_W + 0.04\, E_H$$

Most estimates of E_H are low (see Section IV), and it is multiplied by a small factor, so its contribution to the LSI is small.

As $E_H \rightarrow 0$, we get a maximum estimate for the value of E_W (the effectiveness of the average PFD in ARM when worn):

$$0.133 \geq 0.24\, E_W$$

$$0.55 \geq E_W$$

Using this value, along with the assumed wearability (maximum value observed = 0.58), accessibility (maximum value observed = 0.53), probability of donning (maximum P_D observed = 0.66), and assuming $P_H = 0.04$ and $E_H \simeq 0.2$,[1] the maximal LSI for PFDs used in ARM is:

$$\text{Maximum LSI in ARM} = [0.58\ (0.55) + (0.53)(0.66)(0.55) + (0.53)(0.04)(0.2)]\ 0.997 = 0.514$$

All three sets of estimates from Section 6.2 were plotted against average LSI from ARM in Figure VI-11. The mean benefit estimate at the minimal and maximal LSI values for PFDs in ARM were also computed and plotted. For each of the four sets of data, there was a statistically significant (via t-test, $p < 0.05$) linear relationship between the average LSI and the estimated number of lives saved by PFDs.

[1] This assumption is based upon the fact that the estimates of E_H even in optimal conditions were as low of 0.16, and P_H was used for the PFD with the maximum P_D.

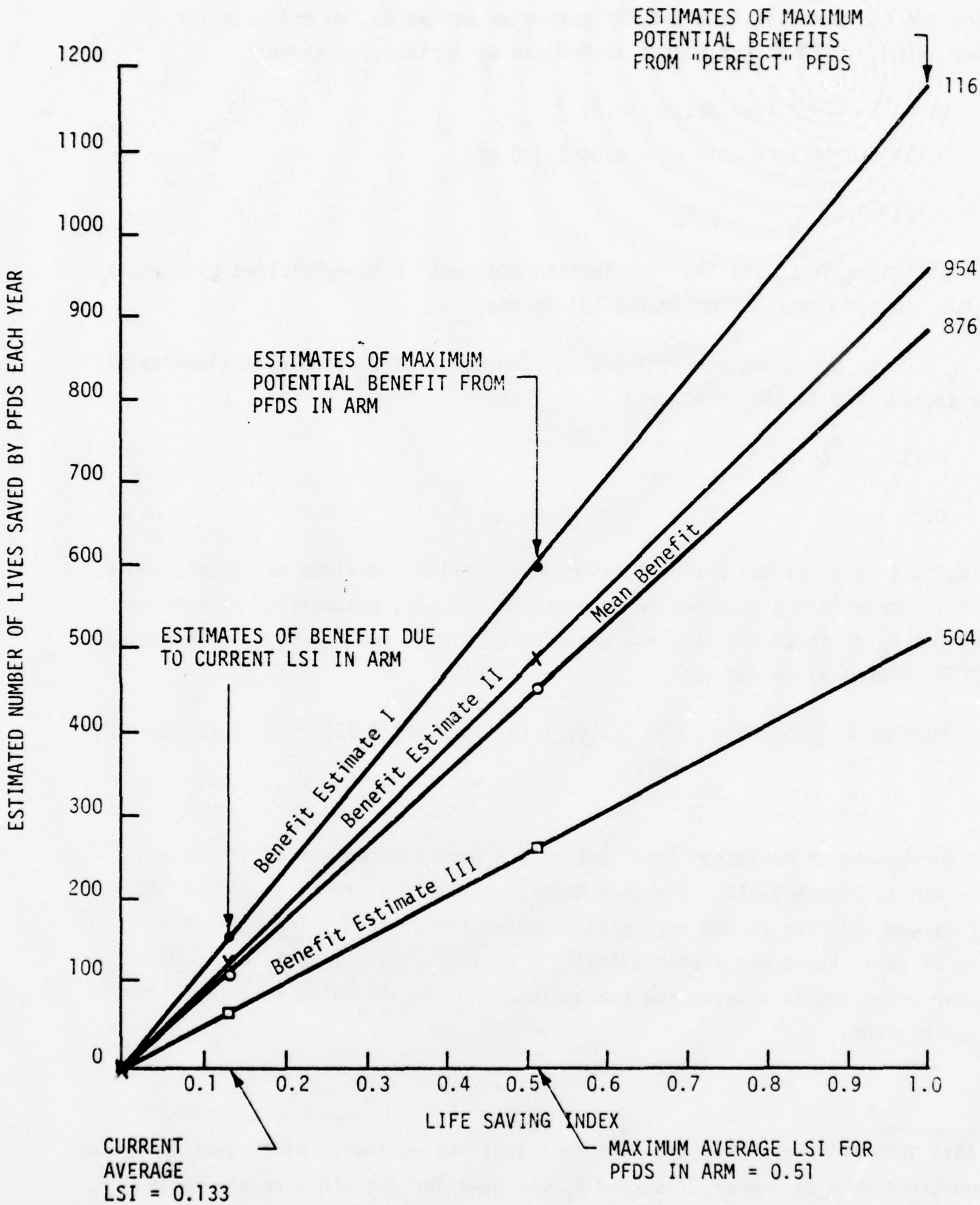


FIGURE VI-11. LSI vs. PFD BENEFITS: THREE BENEFIT ESTIMATIONS AND MEAN BENEFIT

The lines are extended to the theoretical limiting LSI value of 1.0, to show the estimated maximum possible benefits from a population of "perfect" PFDs.

There were approximately 1275 drownings in accidents reported to the Coast Guard in 1975. However, the ARM benefit estimates show that, at best, only 1167 of these would be saved by "perfect" PFDs. There are several reasons why the ARM estimates are lower than the total number of drownings, why the number of reported drownings may be high, and why not all drownings may be prevented by PFDs with a LSI of 1.0.

In both Wyle and Coast Guard studies, it was found that coroners report some boating accident victims as drownings, which are in fact not drownings.[1]

Thus, the 1275 reported drownings are probably high. The ARM benefit estimation techniques are known to generate generally conservative estimates for the benefits of positive programs (see Reference 3). In that way, if ARM predicts a benefit, one can be reasonably assured that the benefit might be larger than predicted.

Not all drownings would be prevented by PFDs in any case. Some people die from physiological problems (heart attack, hypothermia, sudden drowning, etc.) wearing PFDs. Some of the drowning victims who would temporarily be saved by a PFD might die eventually from hypothermia, heart attack, or injuries despite the PFD which prevented their drownings. Some would die of sudden drownings (a physiological problem) since PFDs do not prevent immersion upon impact, and some people have drowned in less than five minutes while wearing PFDs. Finally, some people refuse to use PFDs even when the PFDs are accessible to the people in the water.

The assumptions behind the LSI calculations for ARM allowed for all recoveries using PFDs in the water to contribute to the LSI. In fact, some of these victims may have been saved by other rescue mechanisms (other boaters, boat flotation) and coincidentally have been wearing or using a PFD. If the LSI estimates (current and maximal) for ARM are reduced in Figure VI-11, then the slopes of the lines increase, and the maximal theoretical benefits would increase.

---

[1] For example, one boating accident report was accompanied by a coroner's report listing the cause of death as "drowning" for a probable hypothermia victim who never entered the water.

Finally, there is no way to prevent a boater from removing his PFD, or letting go of it. Even a PFD with an LSI of 1.0 might be discarded in order to swim to shore. Drownings resulting from such behaviors cannot be prevented by the PFD.

For all of the above reasons: 1) there is no guarantee that even if all PFDs had an LSI of 1.0, all drownings would be prevented, and 2) the underestimation of benefits in ARM and the overestimation in the number of drownings in the Coast Guard data may account for many of the apparent drownings that cannot be prevented by PFDs.

The linear relationship between the average LSI in ARM and the benefits suggests that once the impact of a trade-off in PFD characteristics is evaluated in terms of its impact on the average LSI, then the estimates of the impact in terms of lives saved or lost can easily be computed from the mean benefit line in Figure VI-11. Calculations of this type have been performed (assuming the approval of a minimum LSI concept, etc.) and are presented elsewhere in this report (see Section VII).

The estimated benefits, and the benefits predicted by the linear relationship are tabled for the minimal, current, and maximal LSI values from ARM, and maximal theoretical LSI, in Table VI-30. The linear functions display a remarkably close fit to the benefit estimates. Included in the table are the computed coefficients of determination (r^2), measured to three decimal places. For all four sets of data, r^2 attains its maximum value of 1, indicating a strong linear relationship between the average LSI and the PFD benefit estimates from ARM.

The mean benefit of PFDs, as a function of the average LSI is:

$$\text{Number of Lives Saved Due to PFDs} \approx 883 \times (\text{Average LSI}) - 8$$

The simple linear relationship makes cost/benefit analyses for programs designed to increase the average LSI easy once the cost data are obtained. The benefits (using the mean benefit function) are simply 8.8 lives for each 0.01 increase in the LSI.

TABLE VI-30. PREDICTED VS ESTIMATED BENEFITS

BENEFIT ESTIMATE	ESTIMATED FROM ARM	PREDICTED FROM LINEAR RELATIONSHIP WITH LSI
Benefit Estimation I:		
Benefit with Zero PFD Use	0	-7.69
Benefit with Current Use	50	60.37
Maximum Benefit for PFDs in ARM	258	225.32
Maximum Benefit for "Perfect" PFDs	$r^2 = 1.00$	503.99
Benefit Estimation II:		
Benefit with Zero PFD Use	0	-1.74
Benefit with Current Use	123	125.34
Maximum Benefit for PFDs in ARM	490	489.39
Maximum Benefit for "Perfect" PFDs	$r^2 = 1.00$	953.77
Benefit Estimation III:		
Benefit with Zero PFD Use	0	-14.09
Benefit with Current Use	124	143.01
Maximum Benefit for PFDs in ARM	598	593.08
Maximum Benefit for "Perfect" PFDs	$r^2 = 1.00$	1167.18
Mean Benefit Estimation:		
Benefit with Zero PFD Use	0	-7.88
Benefit with Current Use	99	109.63
Maximum Benefit for PFDs in ARM	449	446.25
Maximum Benefit for "Perfect" PFDs	$r^2 = 1.00$	875.64

If more data were made available for particular PFD types, the same analyses could be performed for proposed changes in the design (and LSI) of those particular PFDs.

6.7 Summary of Benefit Estimations

- The multistate analysis techniques have been developed and demonstrated. They require significant insight into the problem area and the ARM data base, as well as objective criteria and procedures for selecting the "best" estimate.
- These techniques were necessitated by the complex and interactive nature of the processes by which people live and die in recreational boating accidents.
- The current annual benefits for PFDs is estimated to be between 50 and 124 lives saved, with the maximum attainable annual benefit being from 258 to 598 lives saved.
- No direct data were available in ARM for estimating the benefits of level flotation (very few level flotation boats were coded in ARM). Therefore, an upper bound of 255 lives saved annually due to level flotation was estimated.
- The estimated potential annual benefit (in lives saved) due to boaters deciding to stay with their boats, when confronted with the options to stay or to leave, is 44 lives (the mean of several estimates).
- It was estimated that between 26 and 202 boating deaths per year are influenced by hypothermia, and a total of 117 to 795 accident victims per year suffer the effects of hypothermia to a significant degree. The ranges on these numbers could not be reduced due to the large numbers of unknown water temperatures and exposures.
- A strong linear relationship was found between the average LSI for the PFDs in ARM and the estimated benefits from PFDs. This linear relationship allows the computation of the effects of changes or trade-offs in PFD design parameters when their effects on average LSI are known.

7.0 ARM CONCLUSIONS

The Accident Recovery Model (ARM) has been developed as an analysis tool, with related techniques and procedures that organizes and summarizes accident data so that the role of personal flotation devices in saving lives can be evaluated and the impacts (in terms of reducing fatalities) of existing and proposed regulatory and educational programs can be assessed. The discussions in this section demonstrate how ARM has fulfilled its dual purpose.

ARM was developed as a versatile and general data analysis model, in response to the complex and interactive nature of the processes by which boating accident victims live and die. The model is empirical, and represents an organized and structured data base. The data were sampled, coded, verified, and weighted in order to accurately mirror the recreational boating accidents for an "average" year.

The basic results in ARM indicated that the ARM data base was representative of the Coast Guard's data, and a thorough examination of those results, variable by variable, pointed out the need for more detailed analyses and statistical techniques in order to examine several variables simultaneously. Problem areas in recreational boating were also identified by the low probabilities of recovery corresponding to victims in parts of ARM.

The detailed analyses revealed significant interrelationships between variables and their effects on a victim's chances for survival. In particular, it was found that PFD wear was highly associated with severe conditions on other variables (water conditions, victim's circumstances, and others). It was shown that ARM could be used to measure the relative importance of PFD properties such as self-actuation of inflatables, the ability to turn an unconscious wearer, the quality of being highly wearable, and effectiveness and reliability over time.

ARM was used to generate quantitative estimates of the benefits of hypothesized and actual changes in recreational boating (changes in PFD wear, changes in PFD properties, i.e., the Life Saving Index, educating boaters to stay with their boats, and the effects of hypothermia and level flotation). The approach of breaking down each problem into multiple factors or states has been proven fruitful in terms of generating meaningful benefit estimates.

ARM has been modified and adopted continuously over the life of this project. The use of the data base and techniques that have been developed require considerable engineering judgment, intimate knowledge of the ARM data base, and insight into the complex and interactive nature of the problems that ARM addresses.

REFERENCES

1. Doll, T., C. Stiehl, M. Pfauth, and R. MacNeill. Personal Flotation Devices Research - Phase I. Final report prepared for the U. S. Coast Guard by Wyle Laboratories, July, 1976, NTIS #AD A037 221.

2. Cohen, S., and R. Giuntini. Regulatory Effectiveness Methodology, Phase II Research. Final report prepared for the U. S. Coast Guard by Wyle Laboratories (in preparation).

3. Cohen, S. Regulatory Effectiveness Methodology, Phase I Research. Final report prepared for the U. S. Coast Guard by Wyle Laboratories, July 1976, NTIS #AD A036 579.

4. Meyer, Stuart L. Data Analysis for Scientists and Engineers. New York: John Wiley and Sons, Inc., 1975.

5. Nie, Norman H., et al. SPSS: Statistical Package for the Social Sciences, Second Edition. New York: McGraw-Hill Book Company, 1975.

6. Hays, William L. Statistics for the Social Sciences, Second Edition. New York: Holt, Rinehart and Winston, Inc., 1973.

7. Hayward, J. S., J. D. Eckerson, and M. L. Collis. Man in Cold Water: Cooling Rate in Heavy Winter Clothing. University of Victoria, Victoria, Canada.

SECTION VII
ANALYSIS OF THE LIFE-SAVING INDEX (LSI) SYSTEM

TABLE OF CONTENTS

SECTION VII LIST OF FIGURES

SECTION VII LIST OF TABLES

SECTION VII
ANALYSIS OF THE LIFE-SAVING INDEX (LSI) SYSTEM

1.0 SUMMARY

Section VII is concerned with the application of the LSI to the PFD approval process. This section starts out with a review of the LSI and a description of its application to three prevalent accident scenarios.

Next, justification is given to:

- Not requiring a priori use of automatic actuators on inflatables. Instead, due to the present reliability problems with automatic actuators coupled with the relatively few cases where automatic actuation would result in additional lives saved, we recommend that the overall LSI be defined such that the capability to automatically provide buoyancy increases the overall LSI. Further work on automatic actuators is recommended.

- Not requiring a priori hypothermia protection or unconscious wearer righting capability (although to achieve the minimum LSI which we recommend, the manufacturer may choose to provide these capabilities).

In light of the above decisions, the wearability, reliability, and effectiveness values were combined into the LSI and are shown in Table VII-2 for typical devices currently in the marketplace as well as inflatables which could be built based on modifications to devices already in the marketplace.

The following points are important:

- The current Type II yoke device, which in 1975 comprised almost 50% of the available devices in use, has an overall LSI of only 0.11, as opposed to over 0.25 for some inflatables, and 0.24 for a Type III vest.

- The reliabiltiy index of feasible inflatables actually exceeds that of many presently approved devices.

- Hybrids (one of which is Coast Guard approved) have the highest overall LSI of currently available devices.

- It should be possible to allow future approval of inflatables with life-saving capabilities twice that of Type II yokes and having individual wearability, reliability, and effectiveness indices also higher than the corresponding indices for Type II yokes.

Next, a discussion of two procedures for allowing the approval of devices based on the LSI is presented and summarized. The more feasible of the two alternatives consists of the implementation of a "Type X" device, in addition to the current Type I, II, III, IV, and V devices. The Type X device would use approval/certification procedures (three alternatives are given) based on the work done under this project. A manufacturer could elect to submit his device for Type X approval if it was not designed to the Type I, II, III, or IV criteria. This approach allows higher life-saving effectiveness devices to enter the market if the public desires them, but does not force anyone to buy a higher potential, but more costly, device than the inexpensive AK-1. Assuming that the Type X devices enjoy a market reception on the order of the reception given to Type III (the costs for Type Xs and Type IIIs would be similar), an increase in adult lives saved of 48 per year is calculated. If the Type X certification program were extended to include children's devices, the benefit would be even higher. The second alternative, requiring a minimum LSI of 0.23 for all PFDs, which produces a predicted benefit of 105 lives per year is presented, but the cost per life saved appears to be high.

One advantage of the Life-Saving Index (LSI) System is that it has the potential of providing significant consumer information on the value of his flotation device. While a number like 0.25 may be selected for the minimum LSI for Type X, the Coast Guard may choose to have classes within Type X of higher LSI devices. As an example:

Type	Minimum LSI
XC	0.25
XB	0.30
XA	0.35
XAA	0.40
XAAA	0.45

could be used whereby manufacturer's advertising and Coast Guard education could be used to inform people of the availability of higher LSI devices. This consumer information would help the manufacturer who chooses to build a high LSI, but possibly more expensive, Type X device as well as the more imaginative manufacturer who may be able to achieve a "breakthrough" with a high LSI, inexpensive device using new materials or actuator technologies. If the above was implemented and technological breakthroughs achieved, a significantly greater benefit than 48 lives per year could be realized.

Next, we present an anaylsis of three alternative approval/certification procedures for the Coast Guard to consider, and the costs for each are computed. The cost of Type X approval is in each case comparable to that for the present approval system.

Finally, a discussion of the possible impact of level flotation on PFD performance criteria is given. Due to lack of data on level flotation boats in the ARM data base (there are very few level flotation boats in the historical data base), the PFD level flotation interaction cannot be analyzed at present using ARM. A more complete analysis using 1978 accident data (which should contain some level flotation boats), is recommended. On balance, we believe that our benefit estimates for the Type X approval are conservative in view of the possible synergistic effects of level flotation coupled with more wearable PFDs.

In summary, this section builds a solid case for the "applicability" of this research within the Coast Guard's PFD approval process. With additional study, it is likely that a more effective means of implementing the LSI concept to save lives will be identified. Our effort to date has concentrated on developing a technology applicable to a more flexible PFD approval procedure. Future phases of the PFD project should be concerned more deeply with optimizing the use of that technology in the Coast Guard's operational PFD approval program.

2.0 THE LIFE-SAVING INDEX (LSI) IN THE ACCIDENT RECOVERY PROCESS

The LSI is a measure of the life-saving capability of PFDs in the process of accident recovery. Accident recovery can be regarded as a system of interacting elements which lead to a person's recovery or loss of life. In order to understand the system, one needs to consider three types of elements and their interrelationships. The elements are the person, the environment, and the equipment. Let us consider the case in which a person has entered the water as a result of a recreational boating accident and his only potential flotation aid is a PFD. The equipment element in this system, then, is the PFD. The LSI is a model which describes the functioning of the equipment (e.g., reliability) and the relationship of the equipment to the accident victim (effectiveness, wearability, accessibility). However, the environment and person elements should also be considered. Two aspects of the environment are clearly important: water conditions (rough, calm) and water temperature. Yet we cannot consider the environment in isolation. It is the relationship of the environment with the person and PFD which is important. Rough water may hamper the effectiveness of the PFD. But PFD effectiveness interacts with the person's condition (conscious, unconscious, or incapacitated) and the person's condition depends partially upon water temperature.

Table VII-1 represents three types of accident recovery circumstances which depend on the condition of the accident victim. The performance required of the PFD in order to produce victim recovery depends on the circumstances. The definitions of some of the parameters which make up the LSI, therefore, change as a function of these circumstances. In Case A the victim is unconscious or incapacitated (e.g., seriously injured) upon entering the water or immediately thereafter. In this case the victim obviously cannot hold onto a PFD or don it in the water; hence the effectiveness of the PFD when held (E_H) is zero and the probability of donning the PFD in the water (P_D) is zero. The effectiveness of the PFD when worn (E_W) is measured using the most severe test procedure. The head forward, stationary test is recommended because the victim could (in the worst case) end up with no headway and with his face forward in the water. This definition of effectiveness for Case A is conservative. For rough water conditions, the head forward, stationary test might be too stringent. Case A also requires that the PFD's buoyancy mechanism work passively (i.e., without manipulation by the victim). This means that the system

TABLE VII-1. DEFINITIONS OF PARAMETERS OF THE LIFE-SAVING INDEX (LSI)

CASE A: VICTIM UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER	CASE B: VICTIM CONSCIOUS UPON ENTERING THE WATER BUT BECOMES UNCONSCIOUS WHILE IN THE WATER	CASE C: VICTIM CONSCIOUS AND REMAINS SO WHILE IN THE WATER
ESTIMATED PERCENTAGE OF ADULT RECREATIONAL BOATING ACCIDENT VICTIMS ANNUALLY		
0.4 - 14.0	1.1 - 7.7	78.3 - 98.5
RECOMMENDED USAGE ENVIRONMENTS		
Significant likelihood of sudden impact, e.g., motor boat racing, high speed water skiing, white-water boating.	Cold water environments with long expected time-to-rescue.	Warm water and/or short time-to-rescue environments.
EFFECTIVENESS		
E_{W_A} = The probability that the PFD turns the unconscious/relaxed wearer to a position with adequate freeboard (head forward, stationary test).	E_{W_B} = The probability that the PFD turns the unconscious/relaxed wearer to a position with adequate freeboard (head forward, moving test).	E_{W_C} = The probability that the PFD maintains the conscious-relaxed wearer in a position with adequate freeboard (head back, stationary test)
$E_H \equiv 0$	$E_H \equiv 0$	E_H = The probability that the PFD maintains a conscious/relaxed user in a position with adequate freeboard when the user holds or lies upon the PFD in the recommended manner.
$P_D = 0$	P_D = The probability that the victim successfully dons the PFD in the water.	P_D = The probability that the victim successfully dons the PFD in the water.
WEARABILITY		
I_W = The probability that the PFD is worn by the victim of a boating accident upon entering the water and continues to be worn while in the water. I_{AC} = The probability that the PFD is accessible to the victim of a boating accident but not worn initially upon entering the water.		
RELIABILITY *		
R_A = Probability that the minimum effective buoyancy is achieved and maintained through the use of inherently buoyant material, automatic actuation of an inflatable, or both	R = Probability that the minimum effective buoyancy is achieved and maintained through the use of inherently buoyant material, automatic actuation, manual actuation or any combination.	R = Probability that the minimum effective buoyancy is achieved and maintained through the use of inherently buoyant material, automatic actuation, manual actuation, or any combination.

* It is recommended that oral inflation and topping-up capability be required on all inflatables and hybrids in all casea as a back-up system.

must have inherent buoyancy or an inflatable component which automatically actuates when submerged in water.

In Case B automatic actuation is not required for inflatables since the victim is conscious and not incapacitated when he enters the water. Manual actuation (meaning the wearer must act to initiate inflation by CO_2 or other system) is recommended. In Case B effectiveness when worn is measured by using the head forward moving test.[1] This test is less stringent than the head forward, stationary test, but still conservative considering the victim's condition. Since the victim is conscious and capable when he enters the water, one might presume that he adopts a head-back position and simply remains in that position even after he becomes unconscious. If one were comfortable with this presumption, the PFD would be required only to maintain the wearer in a head-back position. However, the victim might attempt to swim and become exhausted in a head-forward position, or be buffeted into a head forward position by rough water conditions. The head forward, moving test is therefore recommended.

Table VII-1 considered the effect of the victim's condition on performance requirements for PFDs. In determining the performance requirements, it was necessary to specify water conditions as well as victim's condition. To be on the safe side, we presumed rough water conditions. Rough water tests of PFD effectiveness were not within the scope of this phase of the PFD research project, but should be included in further development work.

The question which must be addressed is "which set of PFD performance requirements should be recommended for Coast Guard approved or certified PFDs?" Each performance requirement discussed above is potentially beneficial (saves lives) under some circumstances. However, if the requirement were extended to all PFDs in all circumstances, it might result in a net loss of lives. For example, requiring all PFDs to have the capability to turn unconscious wearers to the head-back position might compromise wearability to the point that the overall life saving capability of PFDs is reduced. For each effectiveness performance requirement, the trade-off with wearability, reliability, and accessibility must be evaluated. ARM can be used to assess the potential cost or benefit associated with each performance requirement.

---

[1] This test is used in the current PFD approval tests.

2.1 Automatic Actuation for Inflatables

ARM estimates of the proportion of accident victims who enter the unconscious or incapacitated range from 0.004 to 0.140. The latter estimate includes all adult victims coded "unconscious" or "seriously injured," and who may have been "sudden drownings" (Reference 1). Sudden drownings[2] have been attributed to one, or a combination of, the following physiological dysfunctions: a) ventricular fibrilation, b) rapid exhaustion from swimming in cold water, and c) hyperventilation caused by sudden cooling of the skin which may lead to inhalation of water (Reference 2). In this estimate sudden drownings were taken to be any victim who died within the first five minutes after entering the water. Therefore, it includes both victims who suffered from incapacitating physiological dysfunction as well as poor swimmers who may have survived long enough to allow them to manully actuate an inflatable PFD. Due to the latter victims, the 0.140 estimate may be high. The 0.140 estimate may also be high because many of "seriously injured" victims suffered injuries such as a laceration of the arm or leg which would not have prevented them from manually actuating an inflatable PFD. On the other hand, the estimate of 0.004 probably understates the proportion of unconscious or incapacitated victims since it includes only victims coded "unconscious" in ARM and excludes anyone coded "seriously injured" or who may have been a sudden drowning. Using the higher estimate (0.140), the number of victims who enter the water unconscious or incapacitated yearly is 779. Of these, about half (389) are recovered. Of the recoveries, only 7.8% or 40 victims were wearing PFDs. Many of these 40 victims were saved by factors other than or in addition to their PFDs (e.g., their ability to swim, boat flotation, assistance from other people, etc.). If we assume that half of these victims would have been saved without a PFD and that 10% of the victims would wear inflatable devices, then $40 \times 0.5 \times 0.1 = 2$ surviving victims need automatic actuators. Using a similar analysis procedure, it can be shown that two of the incapacitated fatalities might be saved by inflatable PFDs having turning moment capability plus automatic actuators. If a 60% automatic actuator reliability is assumed, a net difference of 2.4 lives saved by automatic actuation can be predicted.

Looking at the potential loss side, several factors argue against requiring automatic actuators on inflatable PFDs at the current time. One such factor is

[2]The term "sudden drowning" is used to denote a syndrome characterized by usually unexplained deaths shortly after entering the water. These deaths are not necessarily true drownings.

the problem of entrapment under water (e.g., under an overturned boat). This problem is also present for inherently buoyant PFDs. Entrapment victims might be more likely to become disentangled if they are wearing an inflatable PFD which does not automatically actuate.

Another very important factor is the reliability of automatic actuators. Most of the currently available automatic actuators suitable for use on PFDs suffer from problems of inadvertent operation (from humidity or spray) and failure to inflate when submerged. These problems cause some designs to have poor reliability. Another problem which lessens the effectiveness of most currently available types is that they require a long time to inflate. Current designs take up to five seconds to actuate and as long as eight seconds to fully inflate the PFD (though the inflation time is the same for automatic and non-automatic actuators). Thus, up to 13 seconds elapse before they provide full buoyancy. This time would add to the time required to turn an unconscious or incapacitated wearer. Solid state inflators offer potential in this area since actuation and inflation times can be reduced to milliseconds, as they are in automobile air bags. However, further development is required before solid state inflators are suitable for PFDs. They are currently too costly and generate too much heat upon actuation. These considerations suggest that it would not be beneficial to require certified inflatable PFDs to have automatic actuators at this time. However, this recommendation should be reviewed as more reliable and effective actuators at reasonable cost for PFDs are developed.

2.2 The Ability to Turn Unconscious Wearers to a Position with Adequate Freeboard

According to ARM, between 63 and 429 adult victims who enter the water annually in boating accidents would be expected to become unconscious due to hypothermia and therefore might drown if not provided with a device having a turning moment capability. An additional 54 to 366 victims had exposure levels sufficient to cause death to the average person due to hypothermia alone. These later victims theoretically* would not be saved by a turning moment, although they might live

*The word theoretical is used as 38 of the 54 victims, which should have been dead by Hayward's data (see Reference 7; Section VI), actually did live and all wore PFDs, although it is possible that most of the PFDs had turning moments.

longer with one. These victims represent between 1.1% and 7.7% of the adult victims who enter the water in boating accidents. The upper bound (7.7%) was computed by assuming victims for when water temperature or time in the water are unknown are distributed identically to those victims for whom these variables are known. Since the unknowns in this case have a higher probability of recovery than the knowns, they are likely to have been in less severe conditions; therefore, 7.7% is probably a liberal (high) estimate. Of the lower estimate of 63 adults suffering hypothermia, approximately 10 were fatalities. As the intent of this discussion is to determine if we should force Type X PFDs to have hypothermia protection or turning moment (as opposed to simply encouraging it through the LSI calculation), we will elect to use the lower bound estimate of hypothermia victims. Hopefully, the Coast Guard's hypothermia project will provide better data in the future allowing a reevaluation of this discussion during the next phase of the PFD project. Among victims suffering hypothermia, the rate of PFD wear was 0.435. Therefore, the estimated number of victims experiencing hypothermia who could be helped (not necessarily saved) if all PFDs provided adequate turning moment at the current wear rate is four to five. In order to estimate the total potential benefit of requiring all PFDs to turn unconscious wearers, we must also add in the number of fatalities among victims who entered the water unconscious or incapacitated and were wearing a PFD. If we include seriously injured and possible sudden drowning victims as well as victims coded "unconscious" in ARM, the number of fatalities wearing PFDs is 40. This is a liberal (high) estimate. A lower bound on the proportion of victims who are unconscious or incapacitated in 0.004. Since the probability of recovery is about 0.5 and the wear rate is 0.078, this corresponds to about one fatality wearing a PFD. The total number of people now dying annually who might be helped (but not necessarily saved) if all PFDs had adequate turning moment at the current wear rate is therefore between five and 45. The word "might" is used in the last sentence since some of these fatalities may have already been wearing PFDs with adequate turning moment and some might die even if they had a PFD with turning moment (e.g., from hypothermia per se or from injury). A requirement that all PFDs have adequate turning moment would eliminate the most wearable of the currently approved PFDs (Type III vests and jackets). Ironically, these PFDs afford much better hypothermia protection than some devices which have a turning moment (Reference 3). Most important,

however, the wearability of Type III vests and jackets (0.30 and 0.37, respectively) is much higher than those currently approved types which provide a turning moment.

The wearability index for Type I and II PFDs range from 0 to 0.07. The most effective currently approved device tested in the present project was a Type I. Its effectiveness when worn (E_{W_B}) was 0.87 and its wearability (I_W) was 0. Type IIIs now make up 17.3% of the PFDs on board and have an average wear rate of 0.31 (see Table VII-2). Substituting Type Is for these PFDs would change their wear rate to nearly 0. A change in wear rate from 0.31 to 0 for 17.3% of the PFDs now on board would result in at least 16 more deaths per year according to ARM results.

As a rough estimate, 16 - 5 = 11, additional lives would be lost by requiring all PFDs to have adequate turning moment (where "adequate" is defined as that of the Type I tested in this project) assuming only currently approved PFDs are used. The reason for the loss is the concomitant decrease in wear rate. This result points out an important advantage of approving or certifying inflatable and hybrid devices. Such devices can achieve a turning moment comparable to that of Type Is without sacrificing wearability. From Table VII-2, the wearability of three most effective inflatables and hybrids range from 0.30 to 0.35 and their effectiveness indices (E_{W_B}) range from 0.67 to 0.80.

2.3 Conclusion

On the basis of the above discussion, it appears that automatic actuation and turning moment should not be required performance characteristics of all certified Type X PFDs. However, the capability of a PFD to automatically provide buoyancy, to provide hypothermia protection, and to turn an unconscious wearer should be reflected in the LSI. This can be accomplished by defining the overall life-saving capability as a weighted combination of individual LSIs for Cases A, B, and C (see Table VII-1). This approach is developed in the next section of this report. However, more research is required to develop methods for evaluating the reliability of automatic actuators and the thermal protective capacity of PFDs.

As noted earlier, better data on the incidence of hypothermia would improve our ability to evaluate the desirability of turning moment and automatic actuation. The Coast Guard's hypothermia research and development project should be closely followed to see if it can provide more precise data to this project.

TYPE OF PFD	WEARABILITY INDEX I_W	PROBABILITY THAT PFD IS ACCESSIBLE (INCLUDING WORN) GIVEN THAT IT IS ON BOARD I'_{AC}	PROBABILITY THAT PFD IS ACCESSIBLE TO VICTIM BUT NOT WORN INITIALLY UPON ENTERING THE WATER I_{AC}	PROBABILITY THAT AN ACCIDENT VICTIM IN THE WATER SUCCESSFULLY DONS THE PFD GIVEN THAT IT IS ACCESSIBLE P'_D	PROBABILITY THAT AN ACCIDENT VICTIM IN THE WATER SUCCESSFULLY DONS THE PFD GIVEN THAT IT IS ACCESSIBLE, RELIABLE, AND NOT DISCARDED P_D[11]	PROBABILITY THAT AN ACCIDENT VICTIM IN THE WATER LIES UPON OR HOLDS THE PFD GIVEN THAT IT IS ACCESSIBLE AND RELIABLE P_H[11]	EFFECTIVENESS IN PROVIDING $\geq$4" FREEBOARD AND MAINTAINING RELAXED WEARER IN HEAD-BACK POSITION E_{W_C}	EFFECTIVENESS IN TURNING UNCONSCIOUS WEARER TO POSITION WITH $\geq$4" FREEBOARD (MOVING TEST) E_{W_B}	EFFECTIVENESS IN TURNING UNCONSCIOUS WEARER TO TO POSITION WITH $\geq$4" FREE-BOARD (STATIONARY TEST) E_{W_A}[9]	EFFECTIVENESS WHEN HELD OR E_{H_C}
Type II yoke[12]	0.07	0.20	0.13	0.82	0.57	0.13	0.94	0.40	0.00	0.7
Type III vests	0.30[1]	0.37[5]	0.07	0.71	0.50	0.20	0.94	0.07	0.00	0.3
Type III flotation jacket	0.37	0.29	0.00	0.41	0.29	0.41	0.94	0.00	0.00	0.5
Type IV rings/ horseshoes	0.00	0.44	0.44	0.00	0.00	0.70	0.00	0.00	0.00	0.5
Type IV kapok cushions	0.00	0.53	0.53	0.94	0.66	0.04	0.50	0.20	0.17	0.3
Yoke/Collar type inflatable	0.35[2]	0.40	0.05	0.94[4]	0.66	0.04	0.78	0.67	0.28	0.5
Belt type inflatable	0.35[7]	0.41	0.06	0.82	0.57	0.13	1.00	0.00	0.00	0.3
Hybrid vest with about 15 lbs inherent buoyancy	0.30	0.48	0.18	0.44	0.31	0.39	0.94	0.80	0.00	0.6
Hybrid vest with about 10 lbs inherent buoyancy	0.35[3]	0.37[6]	0.02	0.47	0.33	0.37	1.00	0.73	0.00	0.8
TOTALS										

[1]Typical value for Type III vests.

[2]Average of I_Ws for the Secumar, BS-8, BS-10, and 12KL.

[3]This device's I_W was probably under-rated by wear study participants because it was not CG approved. It should be comparable in wearability to Type III vests, hence I_W for Type III vests is used.

[4]The probability of donning in the water and effectiveness when held for the BS-8 were hampered by a strap which hel the open ends of the device together. This design problem could be easily remedied in similar new devices. (Theref the estimates of P_D and E_{H_C} used are those for the Type I foam device which is similar in size and shape to the inflated BS-8).

[5]Average of I_{AC}s for all typically styled Type III vests (excludes Wyle Nos. 301 and 298).

[6]Only limited data (N=1) was available on I_{AC} of the modified Stearns Hybrid, so assume it is the same as the Type III vests.

[7]The wearability of this device was probably under-rated by wear study participants because it was not CG approved a because its concealed actuator probably lessened its perceived effectiveness. It should be at least as wearable as yoke type inflatable, hence I_W=0.35 is used.

[8]Study done prior to implementation of regulation requiring minimum number of wearable PFDs on boats 16 feet in length and over.

\

TO POSITION WITH >4" FREEBOARD (MOVING TEST) B	EFFECTIVENESS IN TURNING UNCONSCIOUS WEARER TO TO POSITION WITH >4" FREE-BOARD (STATIONARY TEST) E_{W_A} [9]	EFFECTIVENESS WHEN HELD OR LAIN UPON IN THE WATER E_{H_C}	RELIABILITY AT THREE YEARS OF AGE R	RELIABILITY IN AUTOMATICALLY PROVIDING BUOYANCY AT THREE YEARS OF AGE R_A	LIFE-SAVING CAPABILITY GIVEN VICTIM IS UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER LSI_A	LIFE-SAVING CAPABILITY GIVEN VICTIM BECOMES UNCONSCIOUS AFTER ENTERING THE WATER LSI_B	LIFE-SAVING CAPABILITY GIVEN VICTIM REMAINS CONSCIOUS LSI_C	OVERALL LIFE-SAVING CAPABILITY LSI [10]	NUMBER OF CG APPROVED PFDS ON BOARD IN OBSERVATIONAL STUDY	ESTIMATED PERCENT OF APPROVED OR CERTIFIED PFDS ON BOARD RECREATIONAL BOATS: CURRENTLY[8] (1975)	ESTIMATED PERCENT OF APPROVED OR CERTIFIED PFDS ON BOARD RECREATIONAL BOATS: ASYMPTOTIC VALUES APPROACHED 20 YEARS AFTER IMPLEMENTATION OF TYPE X WITH MINIMUM LSI = 0.25
40	0.00	0.71	0.9800	0.9800	0.00	0.06	0.14	0.11	267	49.5	26.0
07	0.00	0.30	0.9790	0.9790	0.00	0.02	0.31	0.24	86	16.0	25.0
00	0.00	0.57	0.9790	0.9790	0.00	0.00	0.34	0.27	7	1.3	2.5
00	0.00	0.57	0.9825	0.9825	0.00	0.00	0.17	0.13	35	6.5	6.5
20	0.17	0.30	0.9999	0.9999	0.00	0.07	0.18	0.15	144	26.7[8]	15.0
67	0.28	0.51[4]	0.9835	0.00	0.00	0.25	0.29	0.25	0	0.0	
00	0.00	0.30	0.9366	0.00	0.00	0.00	0.36	0.28	0	0.0	
80	0.00	0.67	0.9999	0.96	0.00	0.28	0.38	0.32 .29	0	0.0	25.0
73	0.00	0.83	0.9941	0.38	0.00	0.26	0.36	0.30	0	0.0	
									539	100.0	100.0

ved. It should be

y a strap which held
ew devices. (Therefore,
nd shape to the

same as the

s not CG approved and
east as wearable as the

[9] There has been some discussion in favor of using the Head Forward Moving Test for Case A as well as Case B (see Table VII-1) in which case E_{W_B} would be substituted for E_{W_A} in the equation for LSI_A (see page VII-16).

[10] The overall LSI is a weighted combination of LSI_A, LSI_B, and LSI_C as discussed on pages VII-14 through VII-16.

[11] The method for computing P_D and P_H is discussed in Section IV-3.3.

[12] AK-1 device.

TABLE VII-2. PERFOMANCE PARAMETERS AND LSIs FOR CURRENTLY APPROVED DEVICES, INFLATABLES, AND HYBRIDS

2

3.0 BENEFIT ESTIMATION FOR ALTERNATIVE PFD EVALUATION PROCEDURES

This section presents preliminary estimates of the potential benefits of alternative PFD evaluation procedures. The figures presented here should be regarded as only rough estimates.

The estimation of benefits requires assumptions as to how the Coast Guard would implement new PFD evaluation procedures, as well as the estimation of many parameters. We endeavored to make the assumptions about the implementation process conform to Coast Guard operational procedures and objectives insofar as information about such procedures and objectives was available. The present report is intended as a point of departure for further discussion rather than a final codification of PFD evaluation procedures. One purpose of this report is to stimulate discussion which will lead to better PFD evaluation procedures.

The estimation of benefits of PFD evaluation procedures was done by interfacing the performance parameters of PFDs with the Accident Recovery Model (ARM). Parameters such as PFD effectiveness, wearability, accessibility, reliability, and the LSI are available as inputs to ARM. Average values of these parameters must first be estimated for the population of PFDs currently on board recreational boats. New values of the same parameters are then generated assuming implementation of the Life-Saving Index (LSI) System. Both sets of values are inputs to ARM. ARM benefit estimation procedures can then be used to calculate the expected number of lives saved under each set of parameter values. This, of course, is a gross oversimplification. The judgment of an experienced analyst is required in both the estimation of average values of PFD parameters and in ARM benefit estimation.

Two types of approaches are available for interfacing PFD performance parameters and ARM. The first approach considered was to interface the parameters of effectiveness, wearability, accessibility, and reliability separately with ARM. For example, an increase in the average wearability of PFDs would imply an increase in wear rate in ARM; an increase in effectiveness might imply fewer people drowning after becoming unconscious according to ARM; changes in reliability should be reflected in the rate of PFD malfunctions coded in ARM. Benefits would

be calculated separately for each parameter change. These estimates would then be combined to give the overall benefit of simultaneous changes in PFD parameters associated with the adoption of new PFD evaluation procedures. This approach involves a number of unique complications and problems:

a) It is not clear how certain PFD parameters should interface with ARM variables; the interfacing therefore requires a great deal of judgment. For example, PFD effectiveness as such is not coded in ARM. Judgments must be made as to how changes in effectiveness would affect the number of drownings of unconscious victims, PFD malfunctions, etc.

b) Many of the accident recovery variables related to PFD performance parameters are unknown in a large proportion of BARs; therefore, the ARM data contain a large proportion of unknowns and the knowns may be biased.

c) The benefit estimates for each PFD performance parameter must be non-overlapping, e.g., some parameter changes may be redundant so that they save the same victims. The combination of separate benefit estimates obviously requires great care.

The second approach to interfacing PFD performance parameters with ARM avoids some of these problems by using the Life-Saving Index (LSI). The individual performance parameters of effectiveness, wearability, accessibility and reliability are first used to calculate the average LSI under alternative PFD evaluation procedures. The average LSI is then related to the ARM probability of recovery [P(R)] for adult victims who enter the water in recreational boating accidents as discussed in Section VI.

The average LSI was calculated for both current PFDs and a new PFD population assuming implementation of the Life-Saving Index System. The first step was the calculation of LSIs for individual kinds of PFDs now on board recreational boats and for PFDs which would be on board after the implementation of the LSI System. The PFDs and their performance parameters are shown in Table VII-2.

Only those currently approved PFDs are included which make up a significant proportion of those PFDs currently on board according to the results of the observational study of PFD use conducted in Phase I of this project (see Section III). In addition, two types of inflatables and two kinds of hybrid PFDs are included in the table. These PFDs represent major types of inflatables and hybrids which would gain certification if the LSI System were implemented. The performance parameter values listed for each type of device represent our best estimate of the value which that type of device would achieve. The values are based on the performance of individual devices tested in this project. However, modified values were used when the performance of an individual PFD was not typical of what that type of PFD would achieve. All the modified values are footnoted; the remaining values are taken from Sections III, IV, V, and VI of this report. Note that I'_{AC} is the probability that the PFD is accessible or worn given that it is on board. The parameter used in calculating the LSI, however, is the probability that the PFD is accessible but not worn initially upon entering the water. I_{AC} can be calculated as follows:

$$I_{AC} = I'_{AC} - I_W$$

where I_W = the index of wearability.

Figure VII-1 shows the logic tree which defines the overall LSI for a PFD. The logic tree identifies three cases, depending on the victim's condition, which require different types of PFD performance characteristics.

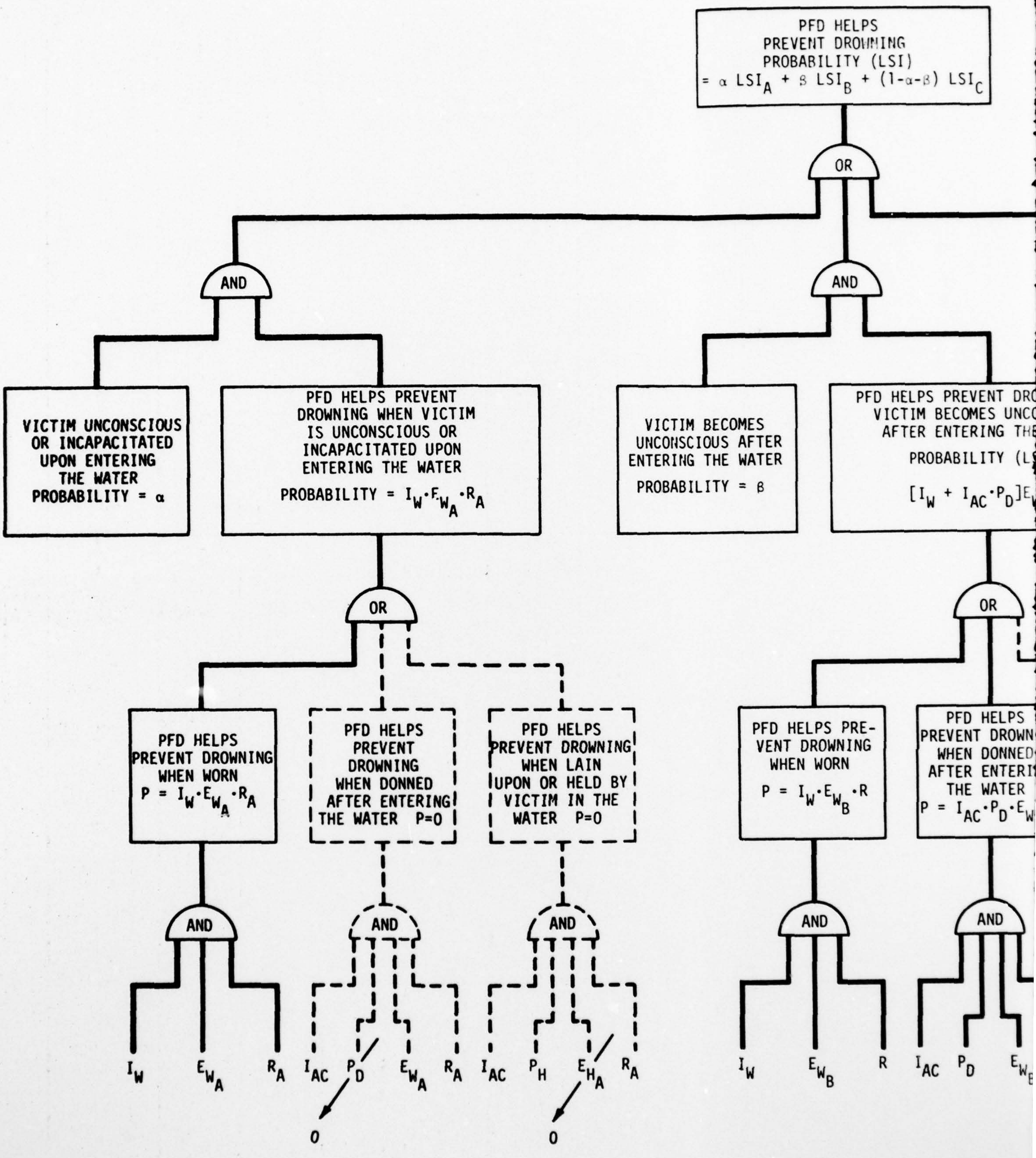
The overall LSI can be expressed as a weighted combination of individual LSIs for three cases:

$$LSI = \alpha \cdot LSI_A + \beta \cdot LSI_B + (1-\alpha-\beta) \cdot LSI_C$$

where

α = the proportion of recreational boating accident victims who enter the water unconscious or incapacitated.

β = the proportion of recreational boating accident victims who become unconscious after entering the water. Once test methods are developed for evaluating the thermal protective capacity of PFDs, this number



PFD HELPS PREVENT DROWNING PROBABILITY (LSI) = α LSI$_A$ + β LSI$_B$ + (1-α-β) LSI$_C$
OR
AND
AND
VICTIM UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER PROBABILITY = α
PFD HELPS PREVENT DROWNING WHEN VICTIM IS UNCONSCIOUS OR INCAPACITATED UPON ENTERING THE WATER
PROBABILITY = $I_W \cdot E_{W_A} \cdot R_A$
VICTIM BECOMES UNCONSCIOUS AFTER ENTERING THE WATER
PROBABILITY = β
PFD HELPS PREVENT DRO
VICTIM BECOMES UNCO
AFTER ENTERING THE
PROBABILITY (L
$[I_W + I_{AC} \cdot P_D]E$
OR
OR
PFD HELPS PREVENT DROWNING WHEN WORN
$P = I_W \cdot E_{W_A} \cdot R_A$
PFD HELPS PREVENT DROWNING WHEN DONNED AFTER ENTERING THE WATER P=0
PFD HELPS PREVENT DROWNING WHEN LAIN UPON OR HELD BY VICTIM IN THE WATER P=0
PFD HELPS PRE-VENT DROWNING WHEN WORN
$P = I_W \cdot E_{W_B} \cdot R$
PFD HELPS
PREVENT DROWN
WHEN DONNED
AFTER ENTERI
THE WATER
$P = I_{AC} \cdot P_D \cdot E_W$
AND
AND
AND
AND
AND
I_W
E_{W_A}
R_A
I_{AC}
P_D
E_{W_A}
R_A
I_{AC}
P_H
E_{H_A}
R_A
0
0
I_W
E_{W_B}
R
I_{AC}
P_D
E_{W_B}

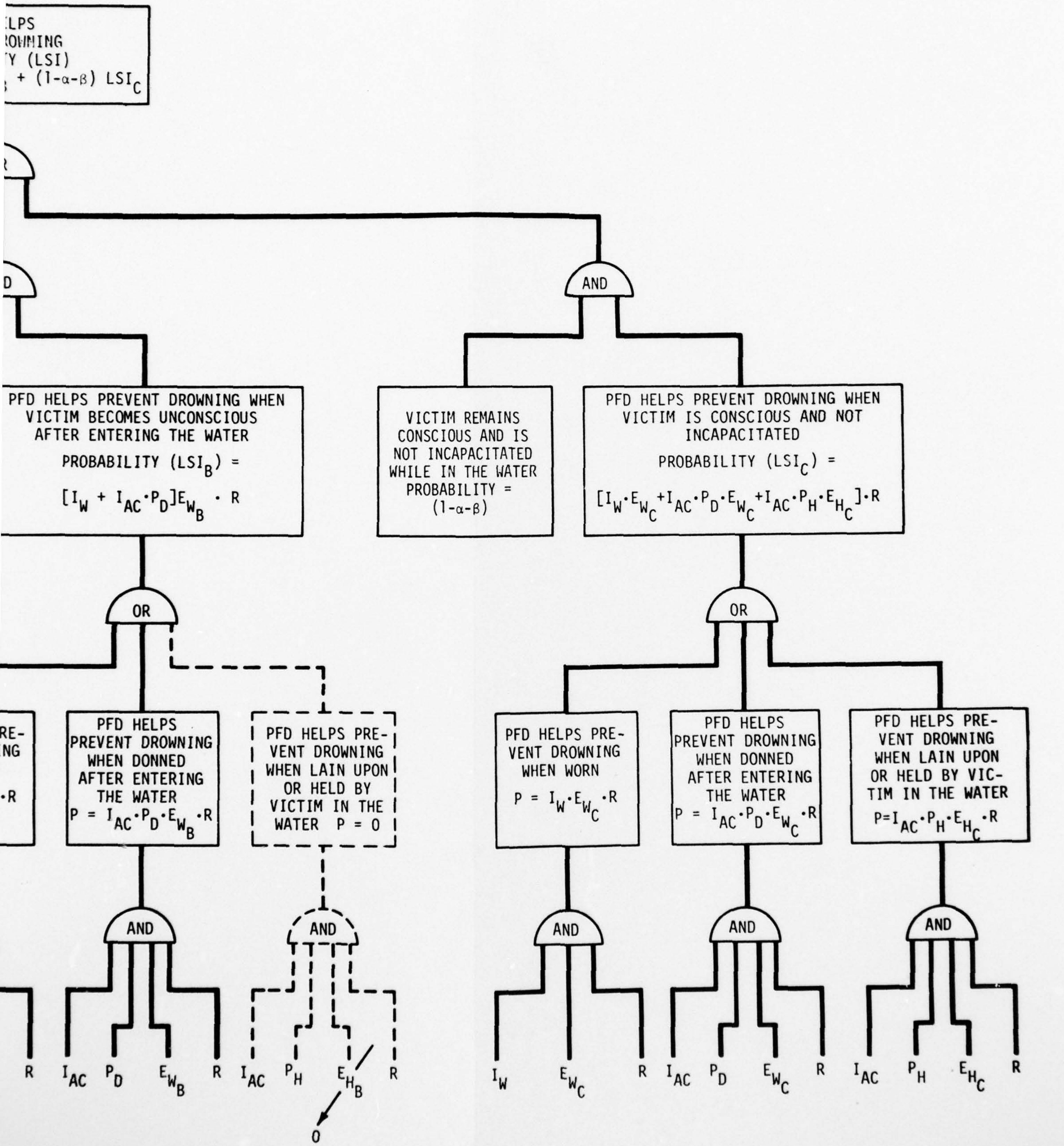


FIGURE VII-1. OVERALL LSI LOGIC TREE

would be modified to reflect the thermal protective performance of the candidate PFD. The higher the thermal protective capacity of the candidate PFD, the lower β would be for that PFD.

$$LSI_A = I_W \cdot E_{W_A} \cdot R_A$$

$$LSI_B = [I_W + I_{AC} \cdot P_D] \cdot E_{W_B} \cdot R$$

$$LSI_C = [I_W \cdot E_{W_C} + I_{AC} \cdot P_D \cdot E_{W_C} + I_{AC} \cdot P_H \cdot E_H] \cdot R$$

In the above formula, R_A is the reliability with which the PFD automatically provides the required buoyancy. R_A is by definition zero for manually actuated inflatables with no inherent buoyancy.

In the above formula, LSI_A, LSI_B, and LSI_C are conditional probabilities. LSI_A is the probability that the PFD helps prevent drowning given that the victim is unconscious or incapacitated upon entering the water. LSI_B is the probability that the PFD helps prevent drowning given that the victim becomes unconscious while in the water. LSI_C is the probability that the PFD helps prevent drowning given that the victim remains conscious while in the water.

ARM results show that the proportion of victims who are unconscious or incapacitated upon entering the water is between 0.004 and 0.140. The proportion of victims who become unconscious due to hypothermia is between 0.011 and 0.077. Although the true values of these proportions are probably closer to the lower estimates, we shall define $\alpha = 0.140$ and $\beta = 0.077$ to calculate the overall LSI. Using the high estimates makes the overall LSI conservative (low) since LSI_A and LSI_B are generally lower than LSI_C.

Further research is needed to develop better estimates of α and β. Further work is also needed to develop test procedures to evaluate the reliability of automatic actuators (R_A) and the hypothermia protection provided by candidate PFDs (which influences β).

An inspection of the LSI columns of Table VII-2 reveals some interesting differences in the life-saving capabilities of various PFDs. The AK-1 model, which makes up nearly 50% of the PFDs on board recreational boats, has the lowest overall life-saving capacility of the PFDs considered in Table VII-2. The AK-1 is high in effec-

tiveness when held and in effectiveness when worn for conscious victims. The main problems which lead to a low LSI are its low wearability and accessibility coupled with low effectiveness in turning unconscious wearers to a position with adequate freeboard (E_{W_B}).

As expected, conventional Type III PFDs have virtually zero life-saving capability when the user becomes unconscious in the water, but high LSIs when the victim can be expected to remain conscious. The Type IV buoyant cushion has a moderate LSI (relative to other PFDs) for cases in which the user becomes unconscious if he has donned it correctly. Although the cushion is relatively low in effectiveness (E_{W_B}, E_{W_C}), its high accessibility (I_{AC}) gives it moderate life-saving capability. The yoke type inflatable and the hybrid PFDs have high life-saving capability both in the case when the victim becomes unconscious and when he remains conscious. Like conventional Type IIIs, the belt type inflatable has zero life-saving capability in cases where the victim can be expected to become unconscious, since it provides no turning moment. However, in the case where the victim remains conscious, it outperforms the conventional Type III devices. The devices with the highest overall effectiveness are the hybrids, particularly the hybrid vest with 15 lb inherent buoyancy.

In order to calculate the average LSI of all PFDs now on board recreational boats, it is necessary to estimate the proportion of the population which each type of PFD makes up. The observational study of PFD wear showed that 49.5% of the PFDs on board recreational boats at the time of the study (July - October, 1975) were AK-1s. Percentages for these types of PFDs are shown in Table VII-2 in the column labelled "Estimated Percent of PFDs on Board Recreational Boats: Currently." The average overall LSI for all PFDs currently on board was estimated by weighting the LSI for each PFD type by the percentage of the PFD population which it makes up and summing the weighted LSIs. The current average overall LSI is:

$$\begin{aligned} LSI = &(0.11)(0.495) + (0.24)(0.160) + (0.27)(0.013) + (0.13)(0.065) \\ &+ (0.15)(0.267) = 0.14* \end{aligned}$$

---

*The average LSI should be in close agreement with the proportion of recoveries among accident vcitims who enter the water and use PFDs. From ARM data, this number is 0.133 (see Appendix VII-B). The slight discrepancy could be due to: a) underestimation of the ARM number due to unreported and/or unknown cases, and/or b) overestimation of effectiveness parameters (E_{W_A}, E_{W_B}, E_{W_C}, E_H) since testing was conducted only in calm water.

In order to estimate the percentage of PFDs of various types that will be on board recreational boats after the implementation of the LSI System, we must first determine:

A. What PFDs will be approved or certified under the LSI System; i.e., what the minimum LSI will be and what (if any) minimums will be established for effectiveness (E_{W_C}) and reliability.

B. How much time has elapsed since the implementation of the LSI System to allow newly certified PFDs to enter the population and PFDs which are inferior to the new devices to be replaced.

C. The sales rate and change in sales rate for each type of PFD.

D. The rate of replacement of each type of PFD.

The benefit derived from the LSI System depends on how it is applied. A number of options are possible, but the following two indicate the breadth of the possibilities (see Table VII-3):

A. Implement the LSI System for all PFD approvals and increase the average LSI by requiring all approved devices to have a LSI of at least X. The problem with this approach is that it would certainly result in the removal of the least expensive PFDs (AK-1s and perhaps Type IV cushions) from the market. This approach is probably unacceptable from a practical viewpoint and preliminary calculations have indicated that it would not be cost-beneficial as well.

B. Implement the LSI System for a new class of devices, which we will choose to call Type X. The minimum LSI for this class could be set at any feasible number, but the number should probably at least equal the LSI for Type III devices. The approval process for presently approved PFDs would remain unchanged, and the new type would be available for manufacturers of advanced devices to use as an approval process.

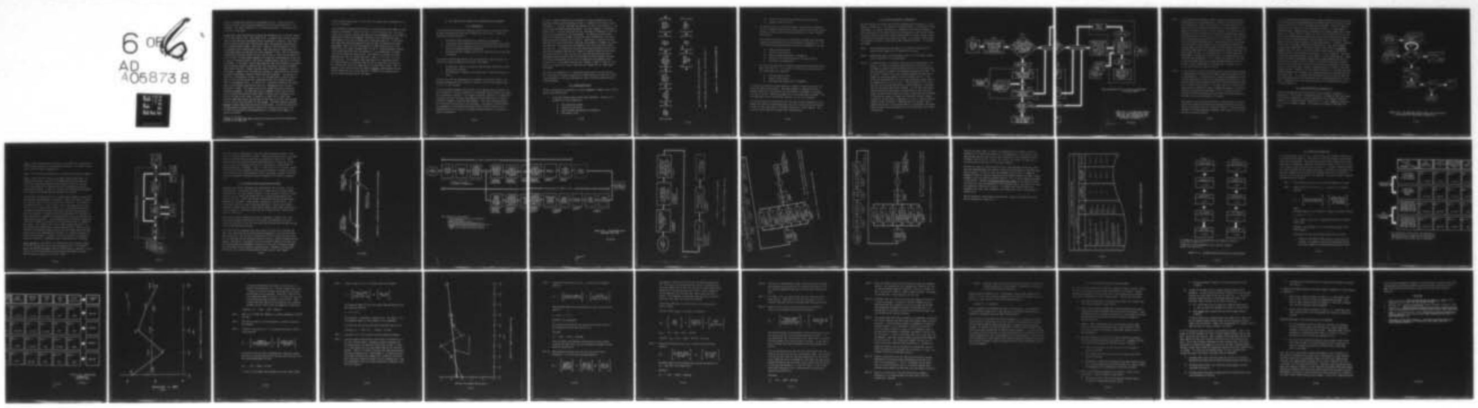
The Type X implementation of the LSI System is the procedure for which costs and benefits will be presented in this section, as the disadvances of the Type A implementation, especially the possible increased cost per life saved, appear to

TABLE VII-3. TWO LSI SYSTEM IMPLEMENTATION OPTIONS

OPTION	ADVANTAGES	DISADVANTAGES
A. Require all devices to have LSI equal to at least 0.23.	1. Raises average LSI, saving approximately 105 lives per year when fully implemented.	1. Removes less-expensive AK-1s and Type IV cushions from market, forcing consumers to pay more for devices. If AK-1s and Type IVs were replaced by Type IIIs and inflatables, added cost to the public could approach $52 million per year.
B. Leave present system for Types I through V intact; establish "Type X" approval for devices not fitting Types I through IV and having an LSI of at least 0.25.	1. Goverment does not force higher PFD costs on anyone; existing devices remain and added costs of devices or Type X are incurred at option of consumers. 2. This is an extension of the same philosophy which resulted in the approval of Type III devices. Type III devices have received excellent market reception and, as will be shown, resulted in the saving of 13 lives per year in 1975, only three years after implementation.	1. Is not guaranteed to raise LSI or save lives unless public buys Type X devices.

AD-A058 738 WYLE LABS HUNTSVILLE ALA F/G 6/7
PERSONAL FLOTATION DEVICES RESEARCH. VOLUME 2. RESEARCH REPORT.(U)
JAN 78 T DOLL, M PFAUTH, J GLEASON, S COHEN DOT-CG-42333-A
UNCLASSIFIED MSR-78-1-VOL-2 USCG-D-41-78-VOL-2 NL

6 OF 6
AD
A058738



END
DATE
FILMED
11-78
DDC

OF 6

8738

make it an undesirable alternative (see Appendix VII-A). Within this Type X approval process, three alternative approval/certification procedures will be presented. All three procedures will yield the same benefit, but produce different costs of compliance.

Assume that a Type X certification process was implemented with a minimum required LSI for that type of 0.25. That number (0.25) is greater than currently approved Type IIIs but less than inflatables should be capable of producing. What would be the rate with which Type X devices would enter the market and what would be their eventual market share? Table VII-2 shows the 1975 distribution of PFDs as computed from our observational study. Note that Type III devices were 17% of the population, yet they were only first approved in 1972. That 17% represents a substantial three year growth for that type of PFD, as relatively few were sold prior to 1972.[3] It would seem reasonable to assume that the percentage of Type IIIs in use will continue to grow in the future, although exactly how much is difficult to estimate. If the Type X devices were approved, they would probably be purchased both by persons currently purchasing Type IIIs and persons currently purchasing other types of devices. Exactly how many Type Xs would be purchased is difficult to estimate. Demand exists for those type devices, as some inflatables are being successfully marketed at present without Coast Guard approval. The success of Type IIIs is encouraging, as their cost is on the same order as that of Type Xs. Type IIIs are currently enjoying a respectable market share competing against the far less expensive AK-1s. In Table VII-2, a possible estimate of the market share of the different type devices after full implementation of the Type X regulation is shown. The figures given are for example only and are based on engineering judgment. The important thing to remember is that Type Xs do not have to achieve any particular market share to justify their existence as the sale of any Type Xs will result in benefits (as their LSI is higher than currently approved devices) and the costs of the Type Xs are only incurred when they are sold at the sole option of the consumer. The Type X approval approach removes a present Coast Guard constraint on the market. It does not create one. The presentation of market share in Table VII-2 is given only so that it can be used to show extent of the possible benefit of allowing large numbers of Type Xs to be sold.

---

[3]Changes in carriage requirements during this period may also have affected the availability of Type IIIs.

Using the market share shown in Table VII-2, an average post implementation LSI of 0.20 is achieved.

Using the benefit equation from Section VI, we can calculate the number of lives saved by an increase in the LSI of 0.06. It is 48 lives per year. As a side-light, using a similar analysis the benefit or the implementation of the Type III regulation in 1975 can be computed. According to our observational study, approximately 17% of the available PFDs in 1975 were Type IIIs. If we assume that those PFDs would have been AK-1s had the Type III regulation not been promulgated, then 17% of the PFD population in 1975 would have had its LSI reduced from 0.24 (Type III jacket) to 0.11 (AK-1). Using the benefit formula, if the whole population had a LSI change of -0.13, approximately 115 fewer lives per year would be saved by PFDs. The "benefit" of having 17% of the population own Type IIIs rather than AK-1s, then, is 0.17 (115) = 20 lives saved per year. As it normally takes many years for a regulation to gain full effectiveness as old devices wear out and are replaced, the saving of 20 lives per year after only three years is a significant savings. This is especially true since the Type III approval removed a market constraint and thus the additional cost of the Type IIIs is borne by the consumer at his option, as would be the case for the Type X.

4.0 COST ANALYSIS FOR ALTERNATIVE PFD IMPLEMENTATION PROCEDURES

4.1 Introduction

Four PFD certification/approval alternatives for the Type X devices have been defined and analyzed for the control sphere activities (cost). These four approaches are the following:

1. Third-party testing program using current test procedures.
2. Third-party testing program using the Life-Saving Index (LSI) System.
3. Self-certification program using the LSI System and with USCG compliance test screening and audit mechanisms.
4. Self-certification program using the LSI System and with minimum USCG involvement.

As we do not know how many devices will be submitted for Type X approval, we used the following assumptions to establish cost bounds:

1. For approach 1 above, we assumed no devices were submitted for Type X approval/certification.
2. For approaches 2 through 4, we assumed 100% of the devices would be Type X.

Once our costs for each alternative are computed, we can weight them for the expected percentage of Type X devices to obtain a cost for the combined Type I, II, III, IV, and X system.

The four programs presented and discussed in this section do not represent the entire spectrum of choices available to the government but are merely four points on a hypothetical continuum. The programs presented, therefore, are representative base line cases that have the capability of being modified by including additional elements or deleting some elements. Thus, many candidate programs can be derived from these base line candidates. The analyses contained herein are intended to provide comparisons among typical options available to the government and at this point only represent the best guesses as to potentially effective approaches.

The control sphere relevance cost tree model for PFDs was presented in the Regulatory Effectiveness Methodology, Phase II - Research first interim report (Reference 4). The cost tree model was reduced to a basic cost equation in view of the three delineated program approaches. The basic equation is presented in Figure VII-2. As can be seen from the cost tree model of Reference 4, there are other costs associated with the PFD programs. In regulatory effectiveness, however, only those cost elements that exhibit cost differentials (cost deltas) from one program to another are of concern. Where there is reason to believe that there will be no cost deltas, then that cost element is dropped from further consideration. This ground rule was adhered to with the exception of product assurance cost. In consultation with both Coast Guard personnel and with certified quality engineers familiar with industrial quality engineering and product assurance practices, it was concluded that there probably would not be any measurable product assurance cost deltas between the three programs analyzed. In the basic cost equation and in the cost tabulation and comparison table (Figure VII-12), the product assurance cost element is shown in order to illustrate to the reader that such an important cost element was not inadvertently overlooked.

The major cost categories (i.e., compliance testing cost, certification cost, etc.) presented in the basic equation are further defined by either cost estimating equations or by flat cost estimates for each of the four program alternatives considered.

4.2 Program Definitions

The four programs will be defined as to their fundamental elements from a control sphere (cost) perspective.

1. Third-party testing using current test procedures - the basic cost categories for this program are:

   - USCG compliance testing
   - Industry certification
   - USCG sponsored manufacturer's information
   - USCG annual visits

$$\left[\text{TOTAL PROGRAM COST}\right] = \left[\text{USCG COMPLIANCE TESTING COST}\right] + \left[\text{AGGREGATE INDUSTRY CERTIFICATION COST}\right] + \left[\text{USCG SPONSORED MANUFACTURERS' INFORMATION COST}\right] + \left[{}^{*}\ \text{USCG ANNUAL VISIT COST}\right] + \left[\text{AGGREGATE INDUSTRY LISTING COST}\right] +$$

$$+ \left[{}^{*}\ \text{AGGREGATE INDUSTRY LABEL COST}\right] + \left[{}^{**}\ \text{USCG AUDIT COST}\right] + \left[\text{PRODUCT ASSURANCE COST}\right]$$

* NOT APPLICABLE UNDER SELF-CERTIFICATION PROGRAM

** NOT APPLICABLE UNDER EITHER THIRD - PARTY TESTING PROGRAM

FIGURE VII-2. BASIC EQUATION FOR PFD PROGRAM COST

- Industry listings with third-party test organizations
- Industry labeling of PFDs

2. Third-party testing using the LSI System - the basic cost categories for this candidate program are the same as those listed for the current program. Of course, the estimating equations will in some instances be different.

3. Self-certification using the LSI System and with USCG compliance test screening mechanism and with an audit mechanism (Alternative 1). This self-certification program consists of the cost categories as follows:

   - USCG compliance testing
   - Industry certification
   - USCG sponsored manufacturer's information
   - Industry listing with third-party test organizations
   - USCG audit of manufacturers

4. Self-certification using LSI System and requiring minimum USCG involvement (Alternative 2). This version of self-certification consists of only three major cost categories:

   - USCG compliance testing
   - Industry certification
   - USCG sponsored manufacturer's information

For analysis purposes the current approach is used as a base line case for comparing the other three programs. The second program is identical with the current program with the exception that the present test methods are replaced with the LSI System. These two programs will not be elaborated on further. The two approaches to self-certification, however, will be fully explained.

It should be noted that the research into self-certification approaches did not address the problem of whether additional legislative authority may be required in order for the Coast Guard to implement some aspects of the programs. This issue was clearly beyond the scope of the research tasks.

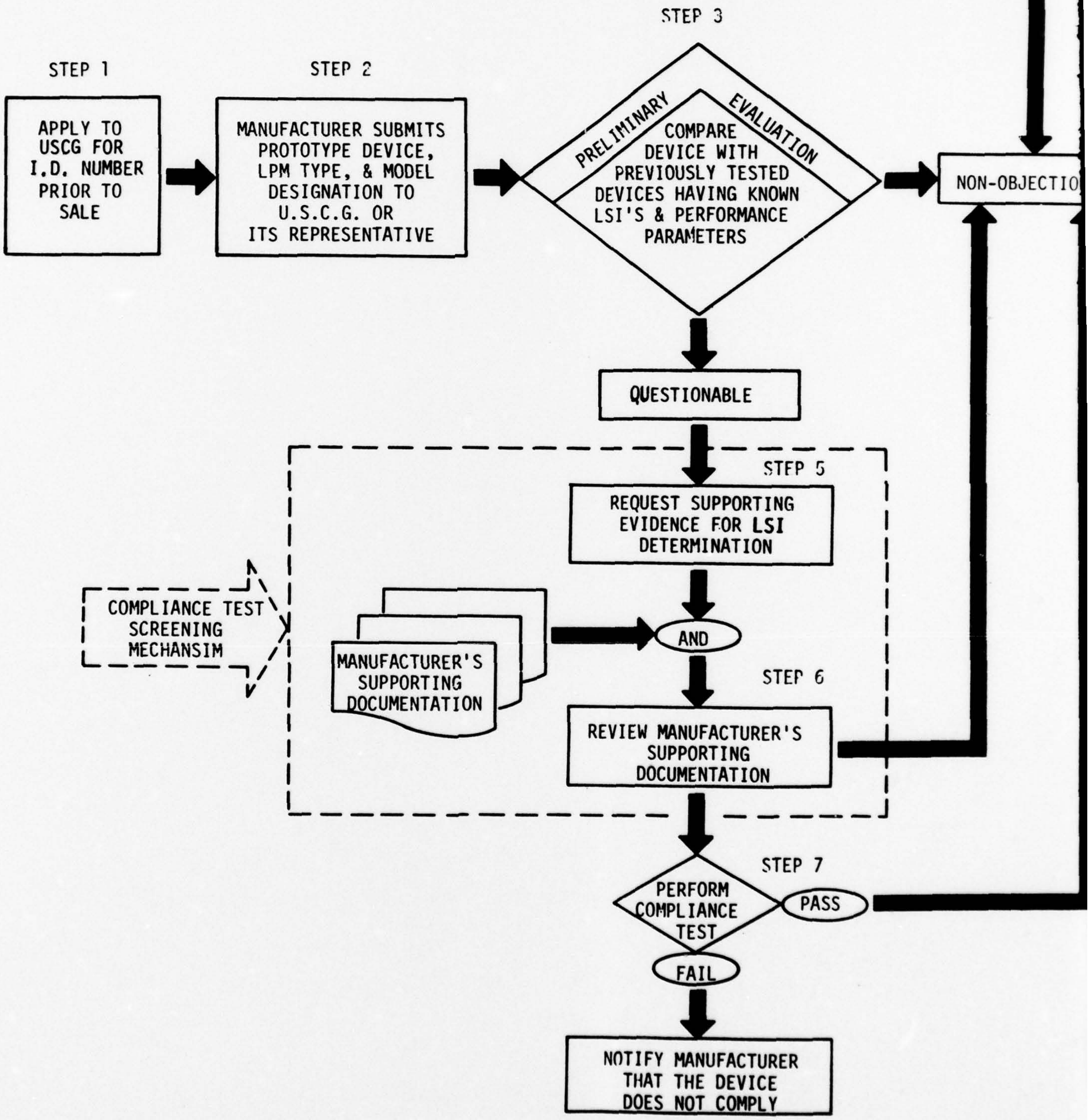
4.3 Self-Certification - Alternative 1

The main features of the self-certification program under alternative 1 is presented in Figure VII-3. This approach is characterized by a high degree of USCG involvement. Its salient features are a compliance test screening mechanism which selectively filters those devices to be tested and an audit control mechanism which provides a periodic review of manufacturers' records, products, quality control, and compliance test authority as well as fine and/or recall powers. This program is similar to that used for boat compliance testing. It functions as follows:

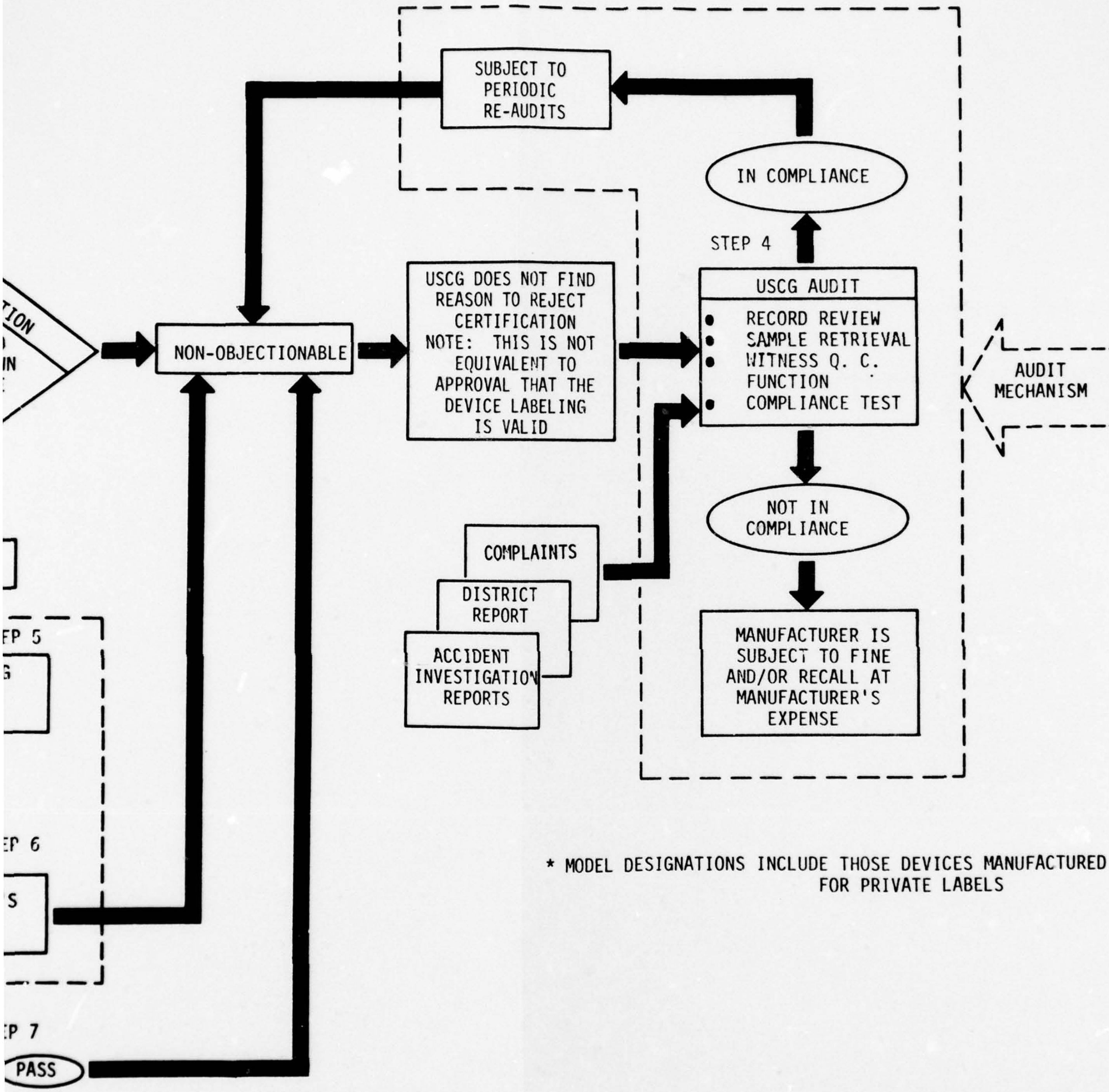
Step 1 - Each PFD manufacturer must apply to the USCG for a manufacturer's identification number prior to marketing his devices.

Step 2 - Manufacturer submits prototype device with its LSI and model designation to the USCG or its representative.

Step 3 - The USCG performs a preliminary evaluation of the manufacturer's prototype. This step is contingent upon the USCG's having empirical knowledge of other PFDs that have been tested via the LSI System and have designated LSI numbers and performance parameters for them. This evaluation is primarily a visual inspection whereby the USCG merely attempts to determine whether a gross discrepancy exists. If the device has the appearance that it has been reasonably labeled then it is categorized as *non-objectionable*. This designation is not synonymous with or in any way equivalent to granting approval or conceding that the advice has been validly labeled. It only means that, based upon the preliminary evaluation, the USCG does not find sufficient reason to reject certification nor to have a compliance test performed. If the USCG has reason to suspect that the device has been labeled incorrectly or that there is something *questionable*, then the USCG can request further information. Depending upon the outcome of Step 3 whether the decision is non-objectionable or questionable, the process leads to either the audit mechanism or to the compliance test screening mechanism.



STEP 1
APPLY TO USCG FOR I.D. NUMBER PRIOR TO SALE
STEP 2
MANUFACTURER SUBMITS PROTOTYPE DEVICE, LPM TYPE, & MODEL DESIGNATION TO U.S.C.G. OR ITS REPRESENTATIVE
STEP 3
PRELIMINARY EVALUATION
COMPARE DEVICE WITH PREVIOUSLY TESTED DEVICES HAVING KNOWN LSI'S & PERFORMANCE PARAMETERS
NON-OBJECTIO
QUESTIONABLE
STEP 5
REQUEST SUPPORTING EVIDENCE FOR LSI DETERMINATION
COMPLIANCE TEST SCREENING MECHANSIM
MANUFACTURER'S SUPPORTING DOCUMENTATION
AND
STEP 6
REVIEW MANUFACTURER'S SUPPORTING DOCUMENTATION
STEP 7
PERFORM COMPLIANCE TEST
PASS
FAIL
NOTIFY MANUFACTURER THAT THE DEVICE DOES NOT COMPLY



* MODEL DESIGNATIONS INCLUDE THOSE DEVICES MANUFACTURED FOR PRIVATE LABELS

FIGURE VII-3. THE COMPLIANCE PROCESS UNDER SELF-CERTIFICATION WITH USCG COMPLIANCE TEST SCREENING AND AUDIT MECHANISMS (ALTERNATIVE 1)

2

Step 4 - If the preliminary evaluation process categorizes the device as non-objectionable, then the manufacturer is subject to future USCG audits on a random basis or upon selective basis. The audit function will enable the USCG to perform a review or audit of the manufacturer's procedures, to witness the quality control process, or to perform a compliance on any of the manufacturer's devices that appear questionable. The audit mechanism function also entails the essence of the compliance test screening mechanism except that it is not limited to one device but to all PFD types manufactured. The audit mechanism is envisioned to be primarily a routine operation of reviewing and witnessing but in cases where accidents have occurred, district reports or complaints have been issued concerning a questionable PFD, then the USCG audit can become highly focused. If the manufacturer of a suspect device has been judged "in compliance" then the status of non-objectionable continues but the manufacturer is still subject to re-audit at any time. If the audit demonstrates that either the manufacturer or one of his devices is not in compliance, the manufacturer is subject to fine and/or the devices are subject to recall.

Step 5 - If the preliminary evaluation indicates that the device being reviewed is questionable, then the USCG can request supporting evidence for the LSI determination. The manufacturer's supporting documentation should include a description of how the LSI designation was determined. New types of PFDs normally would be tested by a third party testing laboratory in order to derive the LSI. For PFDs similar to or identical to those previously tested and rated, a comparative analysis by the manufacturer's own engineering personnel, or by an in-house truncated variation of the LSI System may be sufficient for the manufacturer to estimate, to his own satisfaction, LSI numbers.

Upon review of this supporting information, the USCG makes a decision either to re-categorize the device as non-objectionable or to have a sample of the questionable PFDs compliance tested. If the device does not meet the minimum compliance standards, then the device is re-categorized as non-objectionable.

It is anticipated that the compliance test screening mechanism initially will be more effective while the manufacturers are becoming familiar with the LSI system and particularly with the LSI assignment test procedures. This will require a higher level of USCG activity and is expected to result in a large number of compliance tests. However, after a manufacturer has passed through one of these loops (e.g., Steps 5 and 6 or Steps 5, 6, and 7) with one device, he will, most likely, have learned enough to avoid this process with future devices either by assuring that his device has been classified correctly or by making his data appear to be sufficiently correct to be non-objectionable. It remains, therefore, the function of the audit mechanism to uncover those in the latter category through their random audit. While this system is classified as a preventive system in that its intent is to ferret out many devices that do not meet the standards prior to their getting to the public, it is not foolproof. Therefore, it does rely upon outside inputs to the system to "flag" suspect devices. These flags are accident investigation reports where a questionable device has been involved in an accident, district reports, or complaints concerning a device. Upon receipt of these flags, the USCG can perform a selective audit of the manufacturer's facilities and/or request a compliance test of a sample of the questionable devices. Therefore, in this system (Alternative 1), the compliance test screening mechanism will probably catch some new manufacturers entering the PFD market each year. It is expected that the number of devices that are required to be compliance tested via the compliance test screening mechanism will be very small in comparison with those that are picked up for compliance test by way of the audit mechanism.

4.4 Self-Certification - Alternative 2

The basic flow process for this self-certification program is depicted in Figure VII-4. This program is characterized by a low degree of USCG involvement. In contrast to Alternative 1 which is considered to be a somewhat preventive system *a priori* defect oriented, Alternative 2 is a purely reactive system that is *a posteriori* defect oriented. This system is discussed in the steps that follow:

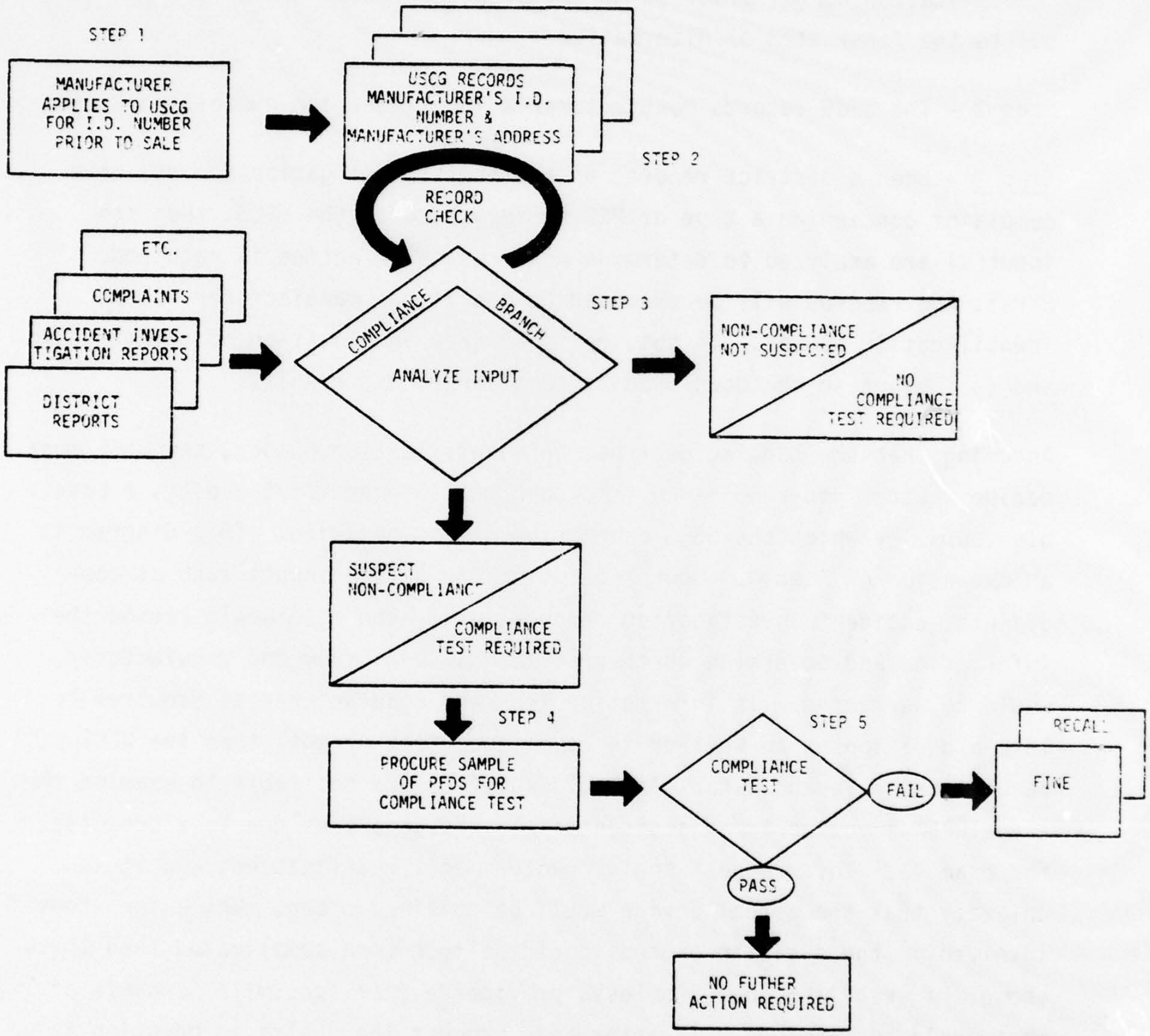


FIGURE VII-4. THE COMPLIANCE PROCESS UNDER SELF-CERTIFICATION WITH MINIMUM USCG INVOLVEMENT (ALTERNATIVE 2)

Step 1 - Each PFD manufacturer must apply to the USCG for a manufacturer's identification number prior to marketing his devices. This step is identical to the first step of Alternative 1.

Step 2 - The USCG records manufacturer's identification number and address.

Step 3 - When a district report, an accident investigation report, or a complaint concerning a type of PFD is forwarded to the USCG, then the input(s) are analyzed to determine what course of action is required. First, the records will be examined to see if the manufacturer has an identification number. If not, he is already in violation of the standard and is subject to shutdown pending compliance test results.

Assuming that the manufacturer has an identification number, the USCG must decide whether non-compliance is suspected. Figure VII-5 depicts a possible course by which the USCG can arrive at its decision. This diagram is an expansion of Step 3. Upon receipt of any of the inputs such as complaints, accident investigation reports, etc., the USCG would review the information and determine whether additional data from the manufacturer would be warranted. If information from the manufacturer is required to make a decision as to whether to compliance test or not, then the USCG will request the relevant data. It could sometimes be desirable to examine the actual PFD involved in an accident if the issue arises due to a drowning, for example. This request could involve legal ramifications and it is unlikely that the actual device would be obtained often. While the steps involved in the decision process could be much more complicated than those shown, Figure VII-5, nevertheless, provides a fair facsimile scenario of what could be involved. If after this process the device in question is suspect of not being in compliance, then a compliance test is required.

Step 4 and Step 5 - The USCG or its representative will procure a sample of the PFDs and perform the LSI System compliance test. If the device passes the minimum requirements then no further action is required. In the event of failure of the device to meet minimum requirements, the manufacturer would be subject to fine and/or recall.

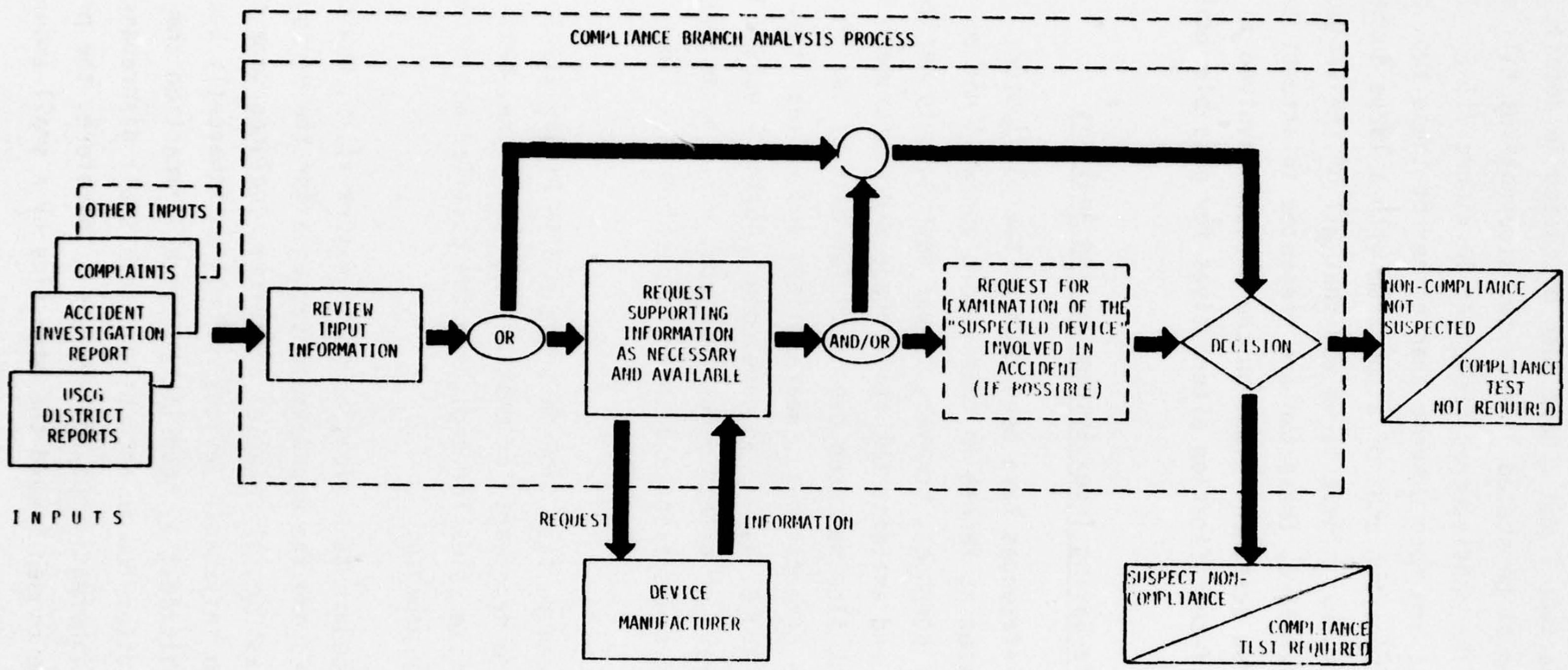


FIGURE VII-5. ANALYSIS PROCESS FOR REACTIVE SYSTEM (ALTERNATIVE 2)

Self-certification Alternatives 1 and 2 have been discussed in detail. Once again, a cautionary note must be stated. These two alternatives fall at extreme ends of a self-certification continuum as presented in Figure VII-6. There could be alternatives that are more extreme than either of these two, but for the most part, they represent two ends of a spectrum with a large number of other possibilities in between. There is no way that all of the various alternatives can be analyzed, therefore, these two are presented in attempt to provoke further interest in an shed pertinent light on the process involved in deriving feasible and workable self-certification alternatives for possible implementation.

4.5 Life-Saving Index System Costing Analysis

Throughout this section references have been made to the LSI System. The LSI System, itself, is discussed at length in this report and will not be further discussed here. For cost purposes, however, it was necessary to derive discrete tasks for the LSI System and estimate the skill grade and approximate time required per task. A task flow has been developed for each of the three major components of the model - effectiveness, wearability, and reliability. Two effectiveness options, A and B, have been developed. Option A uses a human surrogate or dummy to derive an effectiveness measure, while human subjects are used for Option B. These two options and their respective task flows are provided in Figure VII-7.

The wearability test procedure task flow is presented in Figure VII-8. Only gross level breakouts were necessary for costing, and therefore, this over-simplified flow is of little value for depicting the detailed activities involved in the actual wearability process.

The reliability test procedure task flow, shown in Figure VII-9, indicates the major tests and activities and the appropriate sequence for the various accelerated aging tests. The last set of parallel activities includes some tests that will be performed only on inflatable devices or only on inherently buoyant devices. However, these tests, individually, have little overall impact on the total cost and no adjustments were attempted to account for this small discrepancy between the inflatables and the inherently buoyant devices. Therefore, the projected reliability cost could be biased toward the high side by a small amount.

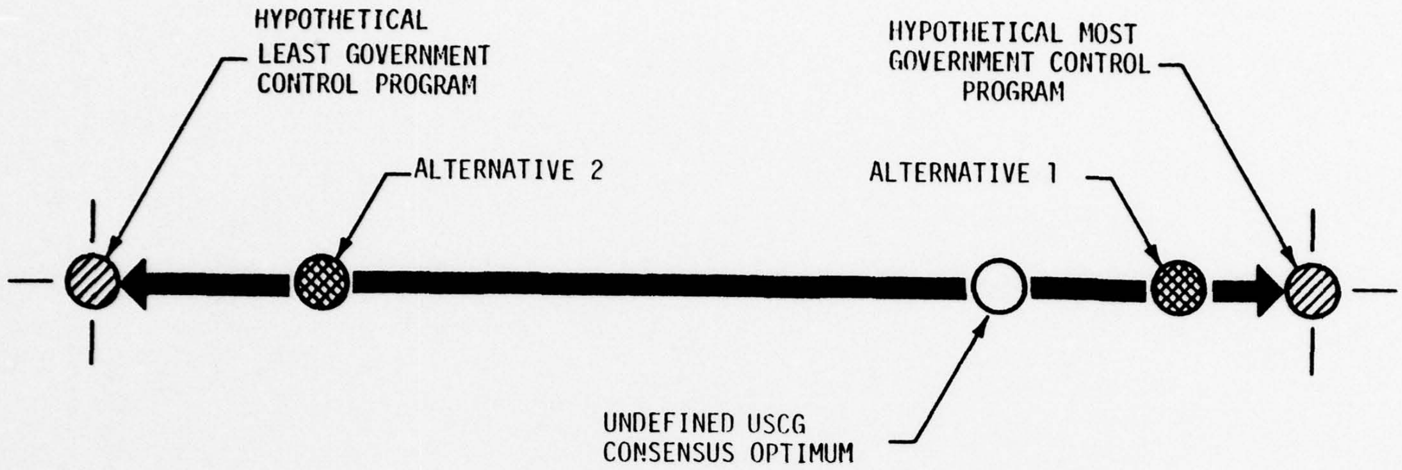
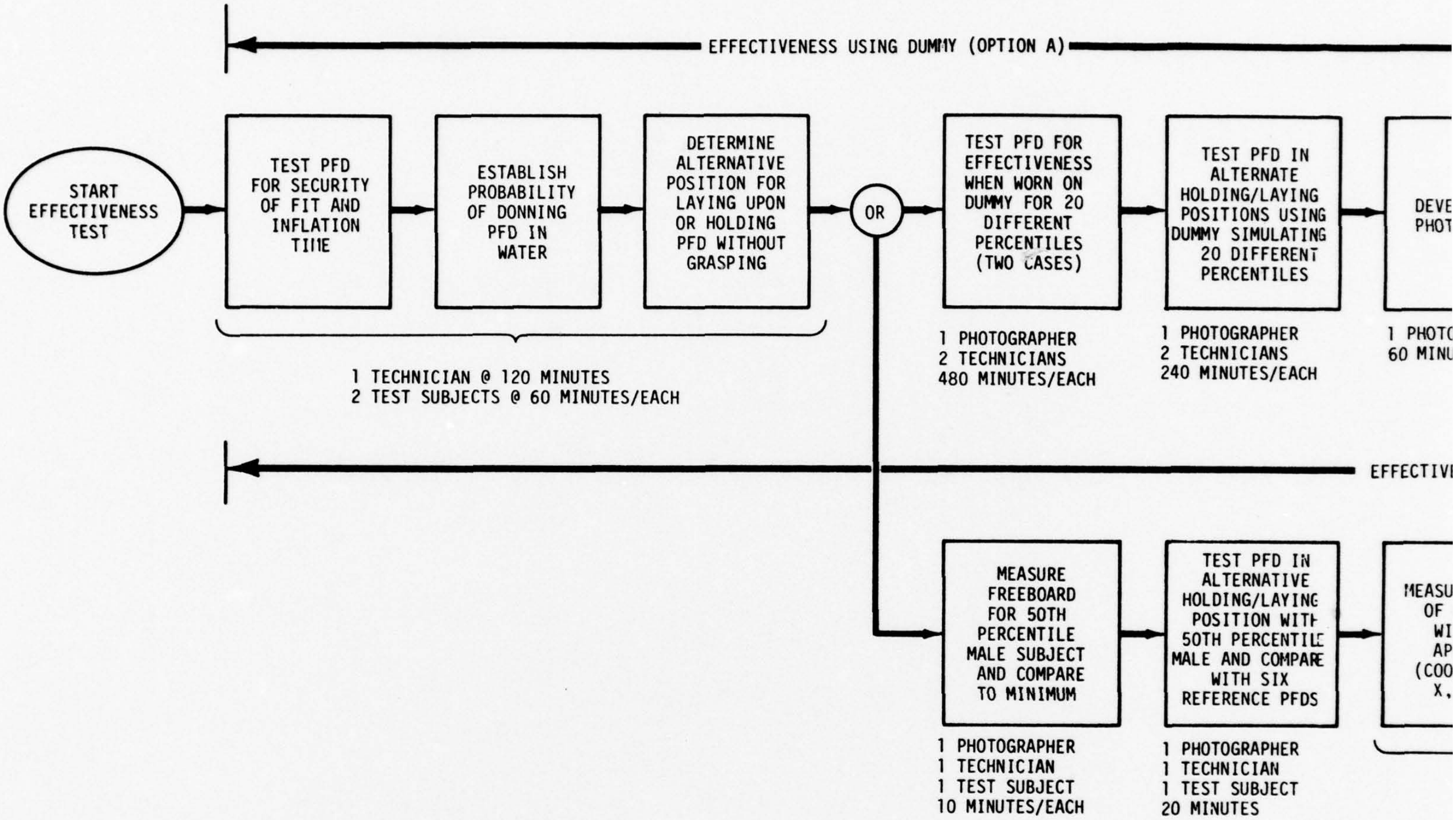


FIGURE VII-6. A HYPOTHETICAL CONTINUUM OF SELF-CERTIFICATION PROGRAMS



NOTE: Additional costs and assumptions:

- Three (3) dummies required at a cost of $5000/dummy (total cost $15,000).
- Expected life of dummy is one year.
- It is estimated that the test organization will run approximately 80 certification or compliance tests per year.
- Therefore, estimated prorated dummy cost per test is $\frac{\$15,000}{80}$ = $187 or rounded to approximately $200/test.

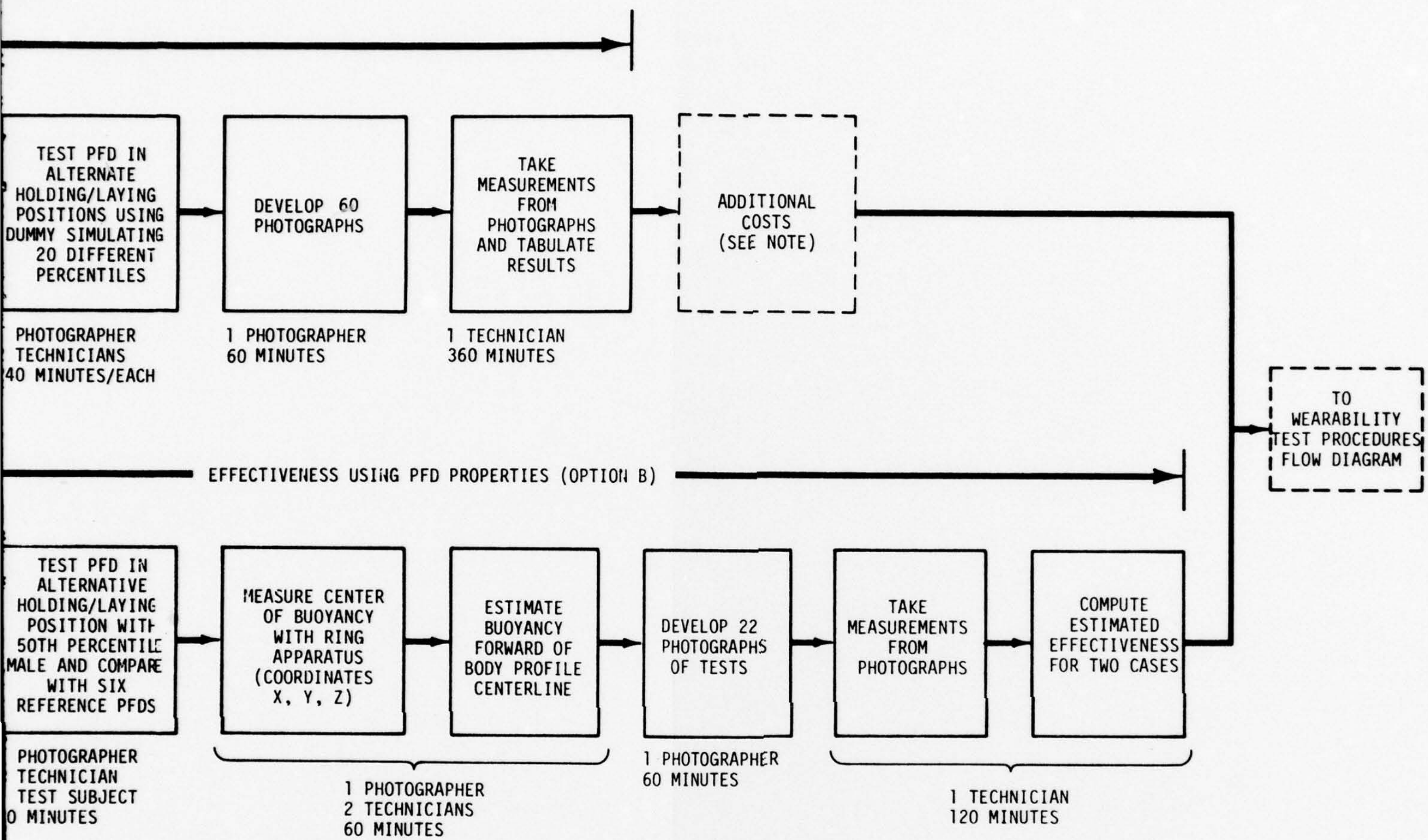
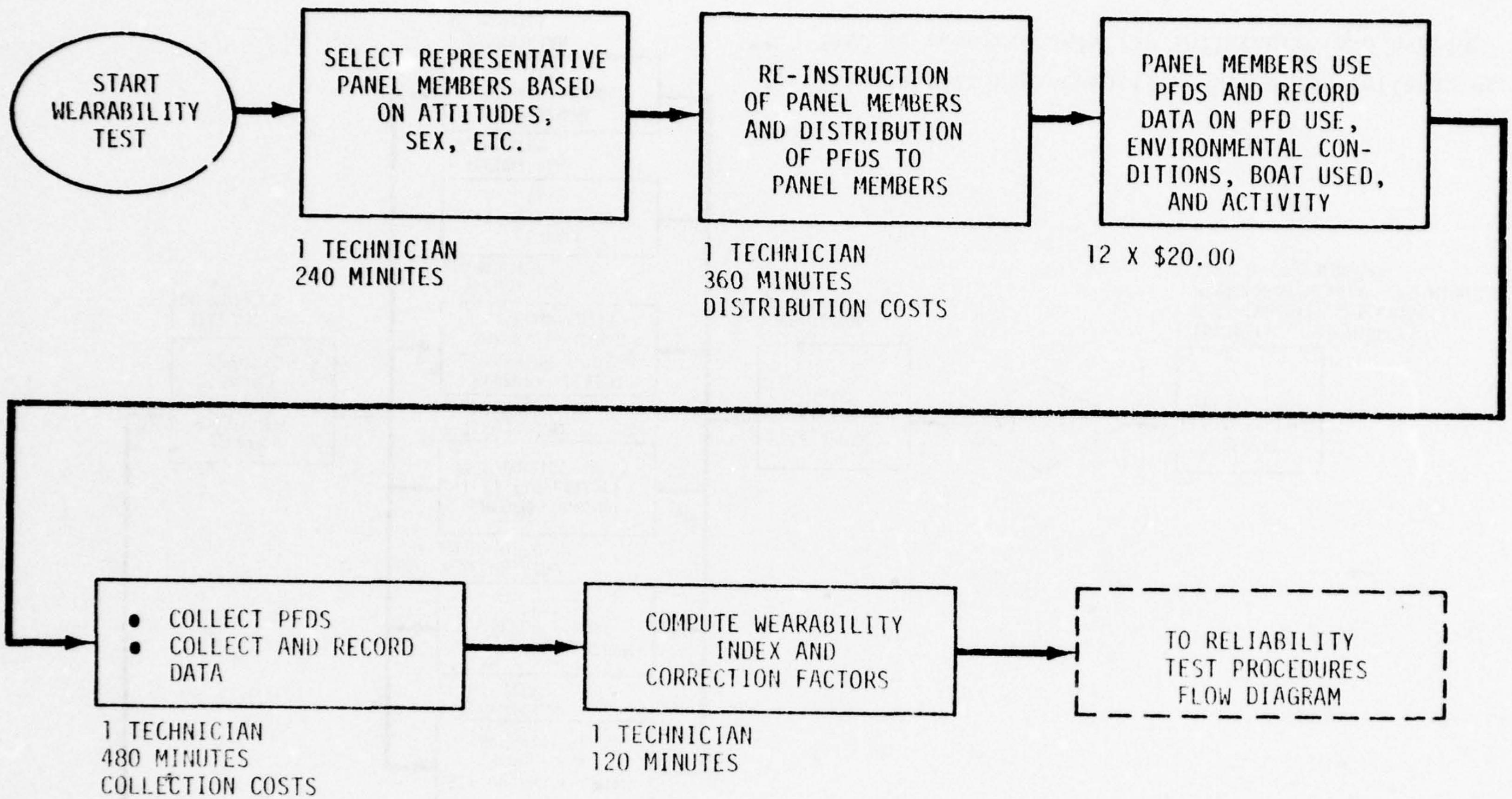
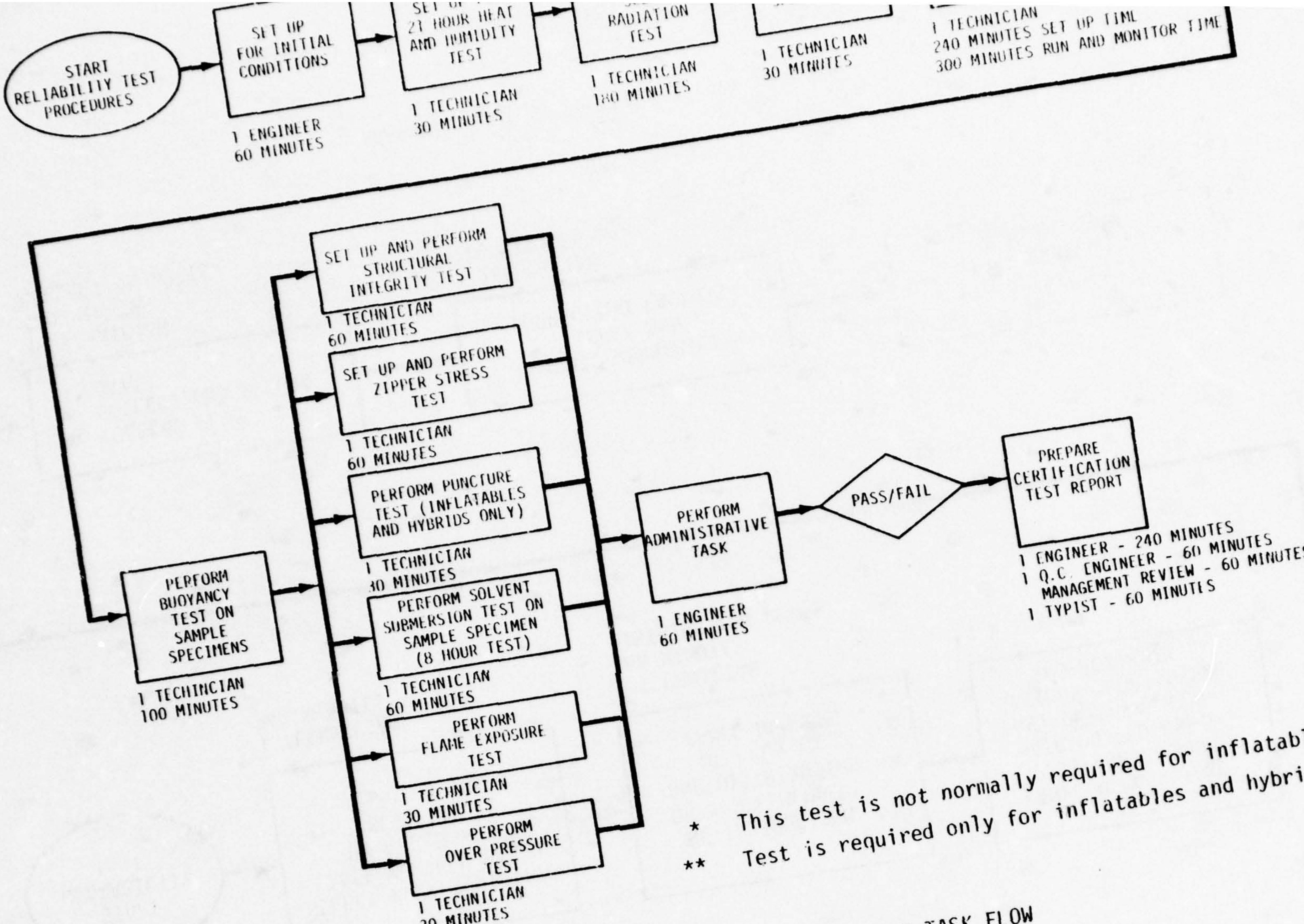


FIGURE VII-7. EFFECTIVENESS TEST PROCEDURE TASK FLOW



WEARABILITY TEST PROCEDURES FLOW DIAGRAM

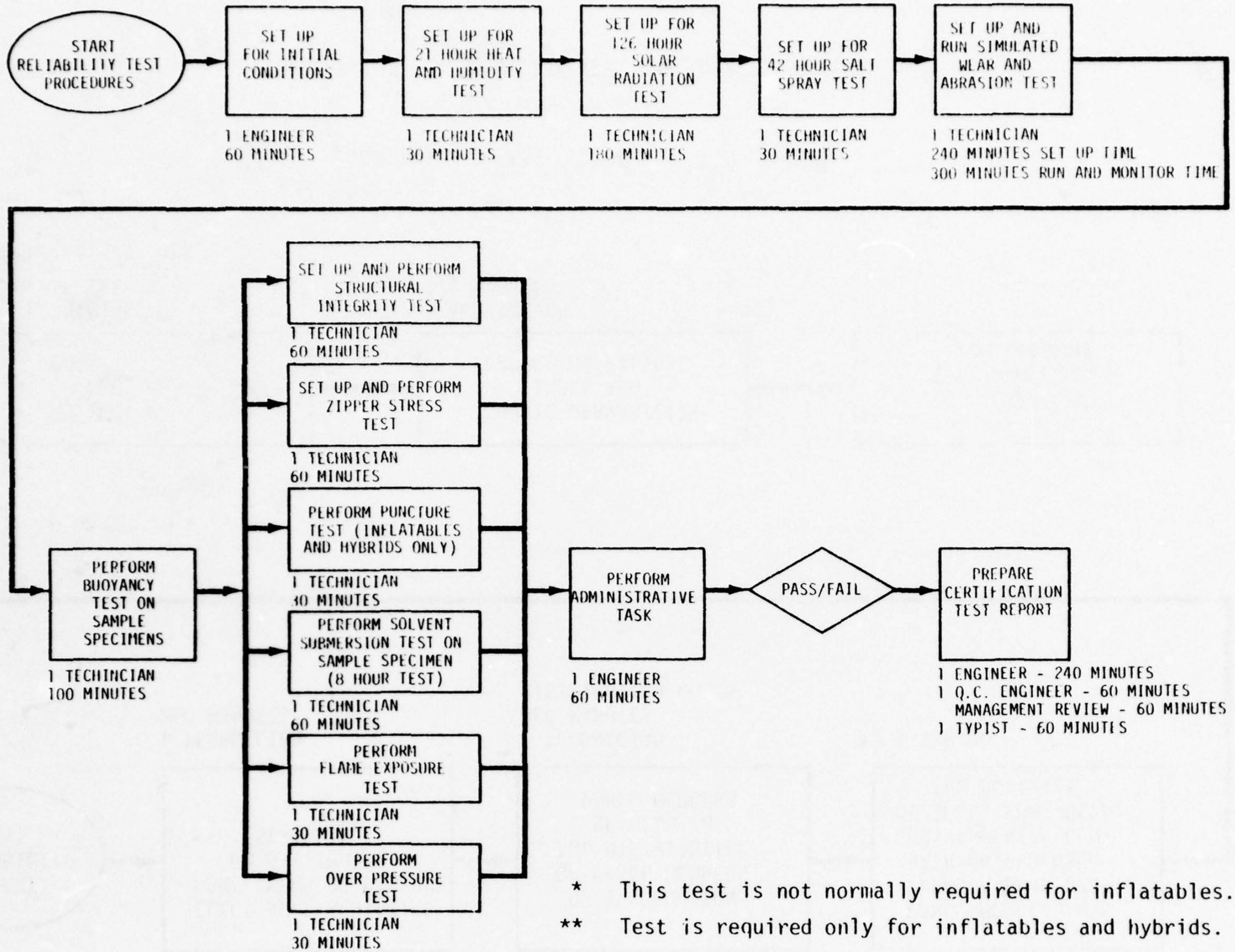
FIGURE VII-8. WEARABILITY TEST PROCEDURE TASK FLOW



* This test is not normally required for inflatables.

** Test is required only for inflatables and hybrids.

FIGURE VII-9. RELIABILITY TEST PROCEDURE TASK FLOW



* This test is not normally required for inflatables.

** Test is required only for inflatables and hybrids.

FIGURE VII-9. RELIABILITY TEST PROCEDURE TASK FLOW

The last two steps shown in Figure VII-9 (determination of whether the device passes or fails, and the test report) are not germane just to reliability. The decision box requires some calculations to combine the three measures of effectiveness by way of the LSI formula. This step is not costed, as shown, since the costs were prorated over the individual measures.

No costs are shown for specialized facilities, test equipment and devices (other than the anthropomorphic test dummies) which could be necessary to test PFDs under the LSI System. In order to cost such equipment and facilities, a number of assumptions would be required regarding the anticipated volume of business flowing through it over the long-term planning horizon. This is clearly beyond the scope of this effort. Therefore, estimated loaded labor rates for the testing industry utilizing facilities and equipment of this type were used to cost each task in the LSI System test procedure flow charts. An example task costing sheet using estimated task times, labor categories, and loaded labor rates is illustrated in Figure VII-10.

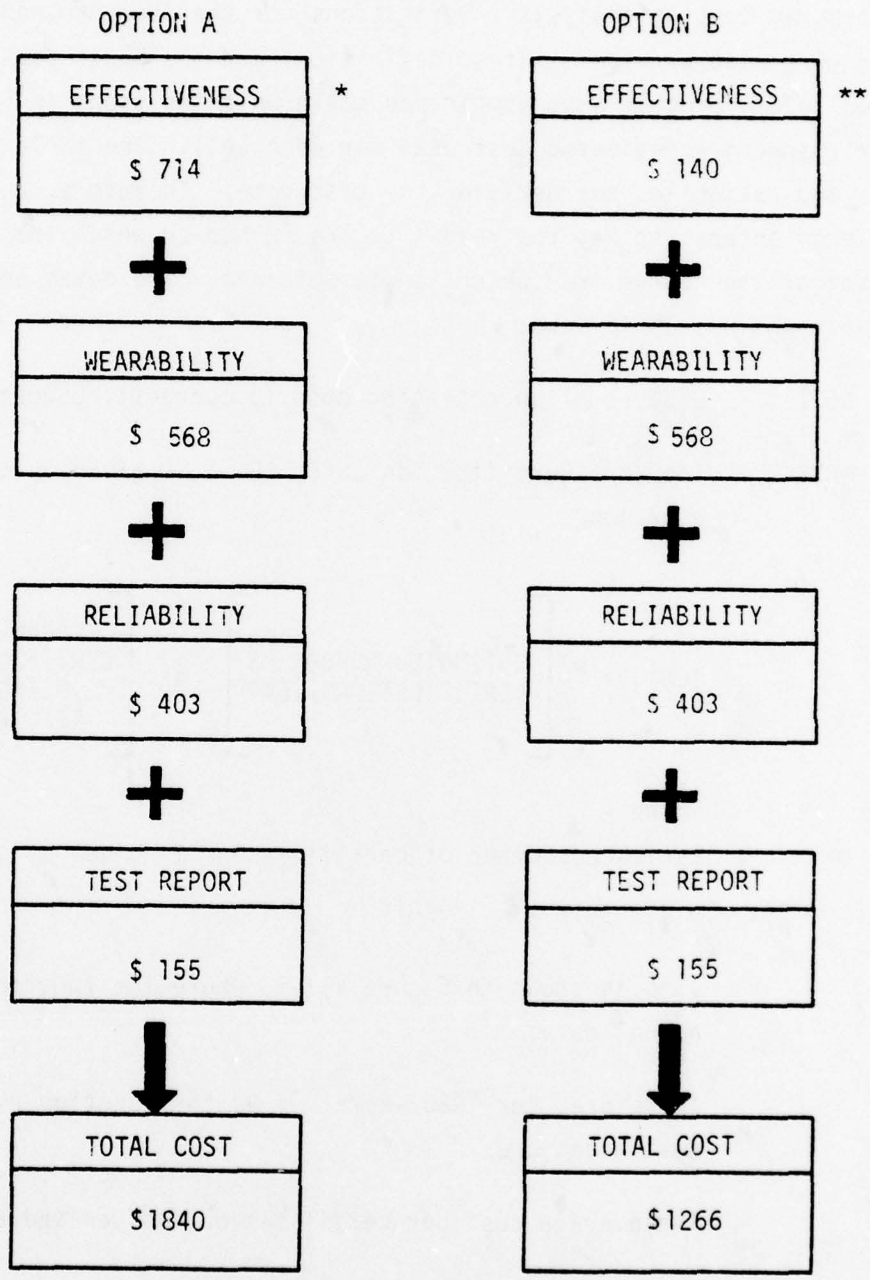
The LSI System was costed under the two options, A and B, previously described and are presented in Figure VII-11.

EFFECTIVENESS TEST PROCEDURES TASK COSTING SHEET

TEST TYPE: *RELIABILITY*

	TASK	LABOR CATEGORY	ESTIMATED TASK TIME (HR)	LOADED LABOR RATE/HOUR	TOTAL COST
1.	*Set up for initial condition.*	*Test Engineer*	*1.0*	*$25.00*	*$25.00*
2.	*Set up 12 hour heat and humidity test.*	*Test Technician*	*0.5*	*$20.00*	*$10.00*
3.	*Set up for three day solar radiation test.*	*Test Technician*	*3.0*	*$20.00*	*$60.00*
4.	*Set up for 24-hour salt spray test.*	*Test Technician*	*0.5*	*$20.00*	*$10.00*
5.	*Set up and run simulated wear and abrasion test*	*Test Technician*			
6.	*Perform buoyancy sample specimen*				

FIGURE VII-10. EXAMPLE OF TASK COSTING SHEET



* Includes the cost of anthropomorphic test dummies as detailed in the note on Figure VII-7.

** Option B is not recommended at this time for technical reasons (see Section IV).

FIGURE VII-11. ESTIMATED COSTS FOR THE TWO LSI SYSTEM OPTIONS

4.6 Program Cost Comparisons

In the introduction (Section 4.1), a basic equation was presented (Figure VII-2) for program costing analysis. Definitions for the four programs under consideration were also provided. These definitions and the basic equation were transformed into a program cost comparison table which is shown in Figure VII-12 with their respective estimated cost data for each cell. The table requires explanations and rationales for deriving the cost data. Therefore, a "note number" has also been entered to key the reader to the method by which the estimate was derived or the source from which it was obtained. The notes and their respective explanations are as follows:

NOTE 1 USCG compliance testing cost is currently budgeted at $35,000.

NOTE 2 Industry Certification cost, ICC_1, is given by the following equation:

$$ICC_1 = \left[\begin{array}{c}\text{ESTIMATED NUMBER OF}\\ \text{CERTIFICATIONS/YEAR}\end{array}\right] \bullet \left[\begin{array}{c}\text{AVERAGE COST PER}\\ \text{CERTIFICATION TEST}\\ \text{USING CURRENT}\\ \text{TEST PROCEDURES}\end{array}\right]$$

where -

Estimated number of certifications is given by the power function

$$y = 113.12 \cdot x^{-0.0211}$$

This is shown in Figure VII-13 where the function was fitted to actual data.

Therefore, for 1980 where x = 9, the function reduces to 109 certifications.

The average cost per certification was derived as follows:

1. A table of the number of PFDs tested as a group was constructed. For example, there were 48 devices during the time frame covered by the USCG printout that were tested

PROGRAM \ COST	USCG COMPLIANCE TESTING COST	INDUSTRY CERTIFICATION COST	USCG SPONSORED MANUFACTURERS INFORMATION COST	USCG ANNUAL VISIT C
THIRD-PARTY PROGRAMS: THIRD-PARTY TESTING PROGRAM USING CURRENT TESTING PROCEDURES	NOTE 1 $ 35,000	NOTE 2 $ 82,840	NOTE 3 $ 18,000	NOTE 4 $ 40,0
THIRD-PARTY PROGRAMS: THIRD-PARTY TESTING PROGRAM USING LSI SYSTEM	NOTE 1 $ 35,000	NOTE 9 $200,560	NOTE 3 $ 18,000	NOTE 4 $ 40,0
SELF-CERTIFICATION PROGRAMS: ALTERNATIVE ONE — SELF-CERTIFICATION PROGRAM USING LSI SYSTEM AND WITH USCG COMPLIANCE TESTING	NOTE 10 $143,975	NOTE 11 $200,560	NOTE 12 $ 23,000	NOTE 13 ZERO
SELF-CERTIFICATION PROGRAMS: ALTERNATIVE TWO * — SELF-CERTIFICATION PROGRAM USING LSI SYSTEM AND WITH USCG COMPLIANCE TESTING	NOTE 17 $143,975	NOTE 18 $200,560	NOTE 12 $ 23,000	NOTE 13 ZERO

* This alternative may not achieve the same level of compliance (which is unknown) as the current third-party program without higher levels of expenditures for compliance testing than shown in this table.

NSORED URERS TION T	USCG ANNUAL VISIT COST	INDUSTRY LISTING COST	INDUSTRY LABEL COST	USCG AUDIT COST	*INDUSTRY PRODUCT ASSURANCE COST*	PROGRAM COST
000	NOTE 4 $ 40,000	NOTE 5 $ 31,200	NOTE 6 $177,800	NOTE 7 ZERO	NOTE 8 ZERO∆	$384,840
000	NOTE 4 $ 40,000	NOTE 5 $ 31,200	NOTE 6 $177,800	NOTE 7 ZERO	NOTE 8 ZERO∆	$502,560
00	NOTE 13 ZERO	NOTE 14 $ 62,400	NOTE 15 ZERO	NOTE 16 $ 40,000	NOTE 8 ZERO∆	$469,935
00	NOTE 13 ZERO	NOTE 19 $62,400	NOTE 15 ZERO	NOTE 20 ZERO	NOTE 8 ZERO∆	$429,935

FIGURE VII-12. CERTIFICATION PROGRAM COST COMPARISON TABLE

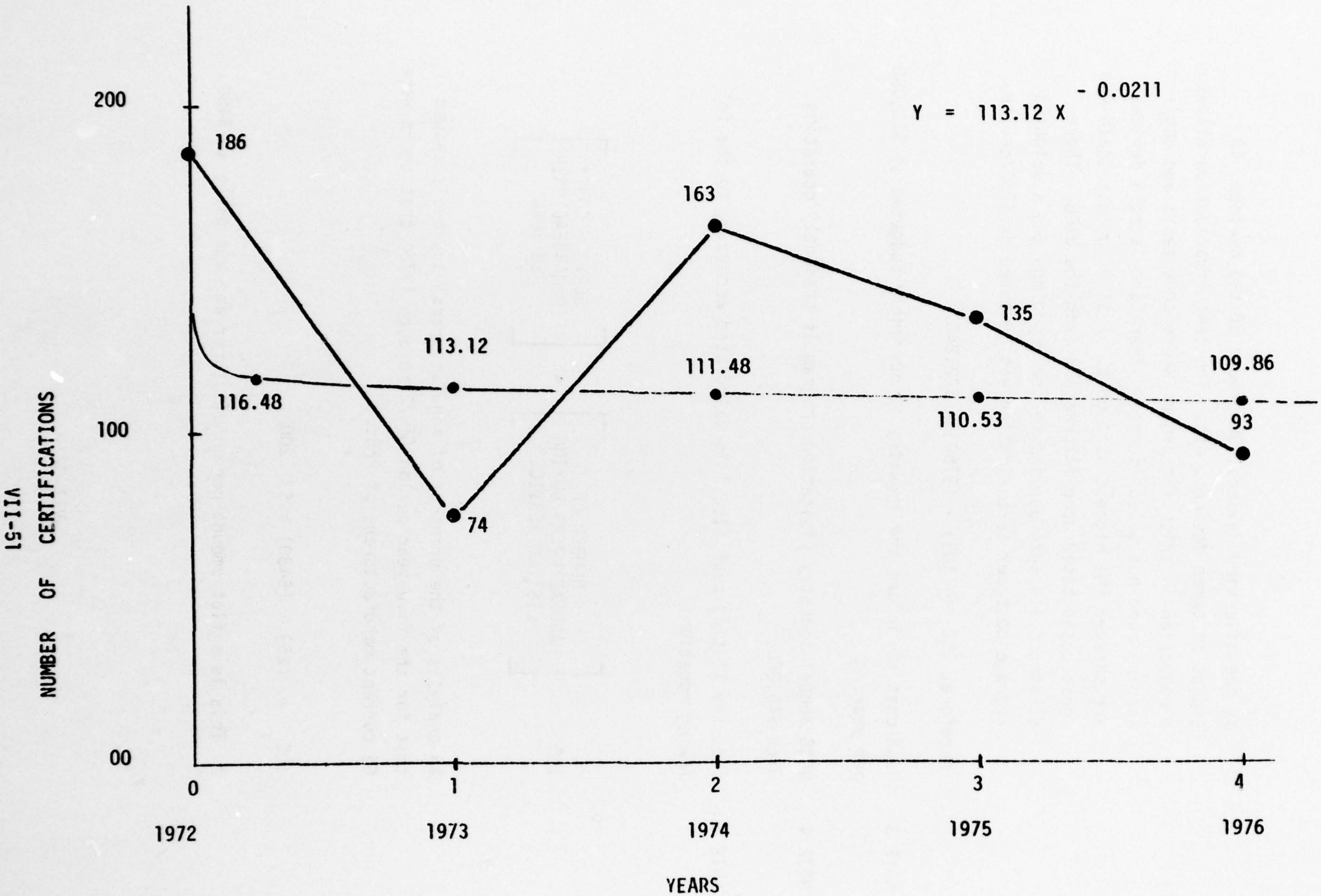


FIGURE VII-13. NUMBER OF PFD CERTIFICATIONS PER YEAR

as one-of-a-kind devices, 38 groups of two devices, 40 groups of three devices, etc. The test organization allows a reduction in price for groups where some tests and engineering need not be duplicated. Therefore, single devices are charged the highest unit cost. A sliding cost scale was constructed based upon information from the USCG. These sliding costs were applied to the groupings and a weighted average cost per certification was computed as $760/device.

Therefore, $ICC_1 = (109) \cdot (\$760) = \$82,840$.

NOTE 3 USCG cost to inform the industry is currently budgeted at $18,000 per year.

NOTE 4 USCG annual industry visitation program is presently operating with $40,000.

NOTE 5 Industry listing cost (ILC_1) is calculated according to the following equation:

$$ILC_1 = \left[\begin{array}{c}\text{NUMBER OF}\\ \text{MANUFACTURERS BUYING}\\ \text{LISTING SERVICE}\end{array}\right] \bullet \left[\begin{array}{c}\text{SERVICE COST*}\\ \text{PER MANUFACTURER}\\ \text{PER YEAR}\end{array}\right]$$

An analysis of the printout of manufacturers' approvals showed that for the five year period (1972 through 1976) that there were 65 current manufacturers of PFDs.

$$ILC_1 = (65) \cdot (\$480) = \$31,200$$

* This is a flat amount per manufacturer and was given as $480.

NOTE 6 Industry label cost (LC) is derived using the following:

$$LC = \left[\begin{array}{c}\text{ESTIMATED NUMBER}\\ \text{OF PFDS}\\ \text{PRODUCED PER YEAR}\end{array}\right] \bullet \left[\begin{array}{c}\text{LABEL COST}\\ \text{PER PFD}\end{array}\right]$$

The estimated number of PFDs procured per year was derived from the regression equation:

$$y = 7.0 + 0.21\ x_i$$

This equation is presented in Figure VII-14. For 1980 ($x_i = 9$). The estimated number of PFDs produced will be 8,890,000.

The label cost per PFD was furnished by the USCG and is \$0.02.

Therefore, LC = $(8.89 \times 10^6) \cdot (\$0.02) = \$177{,}800$

NOTE 7 USCG audit cost is not relevant to the third-party programs.

NOTE 8 Industry product assurance cost should show no differentials in the four programs costed. Companies currently manufacturing inflatable devices are operating under either an FAA, military or UL requirements and have some established quality assurance program. There is no reason to believe that these manufacturers' costs would change due to a USCG standard. As stated previously, the product assurance cost category was included in this table and in the basic equation (Figure VII-2) to indicate that it was not inadvertently left out of the consideration necessary to perform this analysis.

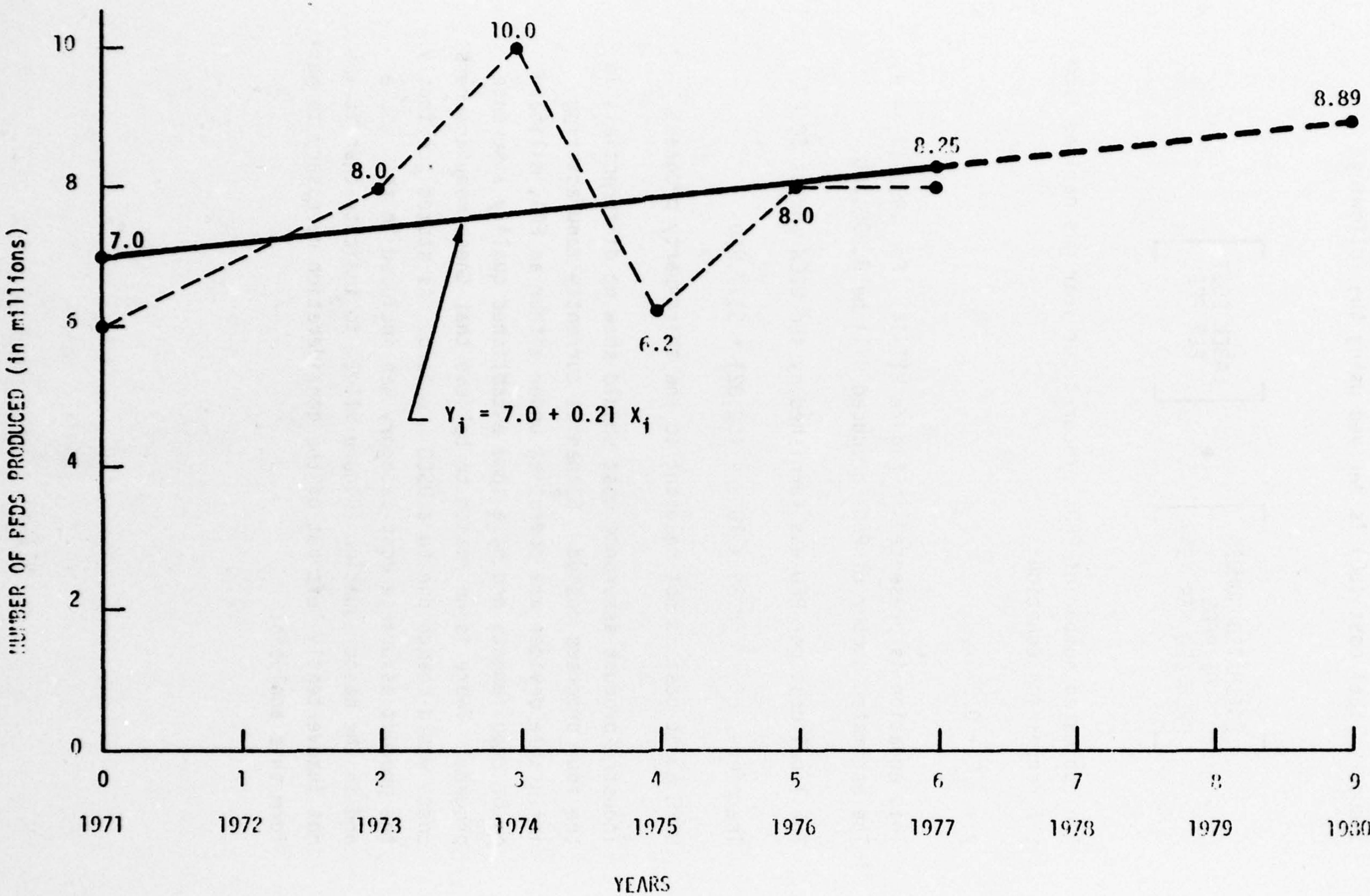


FIGURE VII-14. NUMBER OF PFDS PRODUCED PER YEAR

NOTE 9 Industry certification cost, ICC_2, is given by the following equation:

$$ICC_2 = \left[\begin{array}{c}\text{ESTIMATED NUMBER OF}\\ \text{CERTIFICATIONS/YEAR}\end{array}\right] \bullet \left[\begin{array}{c}\text{COST PER}\\ \text{CERTIFICATION TEST}\\ \text{USING LSI SYSTEM}\end{array}\right]$$

The estimated number of certifications per year is given by the function

$$y = 113.12 \cdot x^{-0.0211}$$

See NOTE 2 for explanation.

The cost per certification test using the LSI System (Option A) was estimated at $1840 (see Figure VII-11).

Therefore,

$$ICC_2 = (109) \cdot (\$1840) = \$200,560.$$

Since inflatable and inherently buoyant devices would undergo virtually the same tests, any cost differentials between the two would be insignificant.

NOTE 10 USCG compliance testing cost, CTC, for self-certification Alternative 1 is given by the following equation:

$$CTC = \left[\begin{array}{c}\text{ESTIMATED}\\ \text{NUMBER OF}\\ \text{COMPLIANCE}\\ \text{TESTS/YEAR}\end{array}\right] \bullet \left[\begin{array}{c}\text{COST PER}\\ \text{COMPLIANCE}\\ \text{TEST USING}\\ \text{LSI SYSTEM}\end{array}\right] + \left[\begin{array}{c}\text{COST OF}\\ \text{PFDS USED}\\ \text{IN TESTS}\end{array}\right]$$

The number of compliance tests per year has been estimated to be 65. An analysis of the USCG-supplied printout of manufacturers' approvals showed that for the five year period (1972 through 1976) there were 65 current manufacturers of PFDs. Some of these did not have devices certified each year, while others certified several. An assumption was made that each would buy one certification per year under the third party programs.

The cost of compliance (or certification) test was previously given as $1840.

The cost of PFDs (C_{PFD}) to be used is provided by:

$$C_{PFD} = \left[\begin{array}{c}\text{TEST}\\ \text{SAMPLE}\\ \text{SIZE}\end{array}\right] \bullet \left[\begin{array}{c}\text{ESTIMATED}\\ \text{AVERAGE COST}\\ \text{PER PFD}\end{array}\right] \bullet \left[\begin{array}{c}\text{NUMBER}\\ \text{OF}\\ \text{MANUFACTURERS}\end{array}\right]$$

$$C_{PFD} = (15) \cdot (\$25) \cdot (65) = \$24,375$$

Therefore, $C_{TCC} = (65) \cdot (1840) + \$24,375 = \$143,975.$

NOTE 11 Industry certification cost, ICC_3, is given by the following equation:

$$ICC_3 = \left[\begin{array}{c}\text{ESTIMATED NUMBER}\\ \text{OF CERTIFICATIONS}\\ \text{PER YEAR}\end{array}\right] \bullet \left[\begin{array}{c}\text{CERTIFICATION}\\ \text{TEST USING}\\ \text{LSI SYSTEM}\end{array}\right]$$

Estimated number of certifications per year was estimated to be 109. (See Note 2 for explanation.)

Therefore,

$$ICC_3 = (109) \cdot (\$1840) = \$200,560.$$

NOTE 12 USCG cost to inform industry under a self-certification program was estimated by USCG personnel to be about $5,000 greater than its present budgeted $18,000 under the third-party testing program.

NOTE 13 The annual visit cost under either self-certification program would be zero. USCG does not feel that the annual visit, as currently employed, would be warranted under self-certification.

NOTE 14 Industry listing cost under self-certification Alternative 1 (ILC_2) can be estimated by the following equation:

$$ILC_2 = \left[\begin{array}{c}\text{ESTIMATED NUMBER OF}\\ \text{MANUFACTURERS}\\ \text{BUYING CERTIFICATION}\\ \text{SERVICE PER YEAR}\end{array}\right] \bullet \left[\begin{array}{c}\text{SERVICE COST PER}\\ \text{MANUFACTURER PER}\\ \text{YEAR}\end{array}\right]$$

The estimated number of manufacturers buying certification service per year was derived from the process described in NOTE 11. It was assumed that the listing service was a good form of insurance and would augment the on-going product assurance. It was, therefore, estimated that about 65 manufacturers would purchase this service.

Cost per manufacturer per year for the listing service was estimated to be double that of the current $480 or $960. The rationale for this was that since the testing organization will not be getting a label fee per unit produced as it now does with the current program and because the LSI system is more costly, the listing fee will be much more expensive. It was felt that, in lieu of more definitive information, a fair estimate would be obtained by doubling the current cost.

Therefore,

$$ILC_2 = (65) \cdot (\$960) = \$62,400.$$

NOTE 15 Label cost under either self-certification program was assumed to be zero. The rationale for this assumption is that the self-certification programs require no labeling. Self-certification, at best, implies self-labeling. Based on other products, the payment of labeling fees is the exception, not the rule.

NOTE 16 USCG audit cost for the self-certification program, Alternative 1, is given as $40,000. In actuality the audit program that was described could incur greater or lesser costs than the $40,000. The $40,000 was the amount allocated to the USCG annual visit program which is not part of the self-certification program, and was transferred to the audit function.

NOTE 17 The premise under which this alternative is predicated is that PFDs will not be tested by the USCG unless they become suspect of being deficient. A device becoming suspect is dependent on complaints, accident reports, etc. as outlined in Figures VII-4 and VII-5. Thus, in actuality, there is no way at this conceptual stage to estimate with any degree of confidence the number of devices that will be tested. In lieu of historical data, only a best guess can be rendered. Under the current program, $35,000 has been budgeted for this activity. This figure would appear to be too low to obtain sufficient compliance under Alternative 2. Alternative 1 compliance testing cost was estimated at $143,975 and since no better rationale can be estimated for Alternative 2, it was, also, assigned $143,975 for compliance testing.

NOTE 18 Industry certification cost for the self-certification program Alternative 2, has been assigned $200,560 which was derived in NOTE 11 for Alternative 1. This is considered to be an upper limit for this alternative since it is doubtful whether manufacturers would behave the same under this much weaker alternative.

NOTE 19 Industry listing cost for the self-certification program, Alternative 2, has been assigned the same value as that for Alternative 1, $62,400.

NOTE 20 USCG audit cost for the self-certification program, Alternative 2, is zero by definition of the program. See narrative discussion of self-certification, Alternative 2.

Referring back to Figure VII-12, if the present system remains unmodified for Types I, II, III, and IV and the compatible third party certification for Type X devices is used, the cost of the entire program would be:

$$384{,}840\ (1-x) + 502{,}560\ (x)$$

where x represents the percentage of Type X certifications. As an example, if x is arbitrarily chosen as 10%, then the cost of the total program would be $396,612 or negligibly more than the existing program.

The intentions of the three certification programs (i.e., third-party testing program using LSI System and the two self-certification alternatives) are that they provide the same or nearly the same level of compliance as the current program. The problem of level of compliance is elusive, since no level of compliance data were available on the current testing program. It is felt that the third-party program using the LSI System and Alternative 1 of self-certification compare favorably with the current method in level of compliance. Self-certification, Alternative 2, could require more intensive compliance testing by the USCG than has been assigned in order to achieve the same level of compliance as does the current method.

5.0 PFD EFFECTIVENESS ON LEVEL FLOTATION BOATS

The level flotation regulation dramatically changes the entire recovery system for recreational boats for which level flotation will be required. The performance requirements for PFDs used on level floating boats may be different than those requirements for basic flotation boats. Consider the following:

1) The level floating boat, if upright, may provide a more secure long-term recovery capability than the PFD.

2) With a level floating, upright boat, the PFD often may only need to support the victim sufficiently for him to return to the boat. Thus, the PFD often will only have to perform for a short period of time and need not necessarily provide sufficient buoyancy to support an unconscious victim.

3) Upright, level floating boats will provide better post-accident access to higher physical effectiveness, lower wearability PFDs which may be stored in relatively inaccessible locations such as bow compartments.

4) The major reasons for the failure of level flotation to prevent a fatality are enumerated below (see Reference 5). (Remember that 81% of the drownings <u>would not</u> be prevented by level flotation):

   a) Cases where the person did not survive for long enough to return to the boat.

   b) Cases where the victim elected to swim to shore rather than return to the boat.

   c) Cases where a person fell overboard and the boat remained intact; or collisions where one boat remained intact; or a person drowned or disappeared with no additional information available.

5) PFDs, or the PFD/boat combination, are effective in many of the above cases. A worn PFD would, in most cases:

   a) Allow the victim to return to the boat and reboard (when it is intact or flooded and floating level),

b) Provide additional flotation if the victim elected to swim to shore.

6) In both of the above cases, a minimum flotation device may be desirable. It would provide sufficient flotation for a long enough duration to allow return to the boat in most cases. It would also provide a flotation boost to the swimmer bound for shore, and a flotation "boost" may well be all that is desired as:

a) All victims who strive for shore are conscious when they do it, and are capable of swimming to at least a limited extent.

b) Many remove bulky flotation devices which impede swimming progress.

A flotation device of minimum buoyancy that added little "drag," and did not impede swimming motions might not be discarded, and would often allow the marginal swimmer, who overestimated his swimming ability when he struck for shore, to make it to safety.

All of the above are based principally on engineering judgment. What is the extent of the PFD combined with level flotation benefit based on the accident data? We do not know directly. ARM is based on historical data and very few boats meeting the new level flotation regulation are in the historical data base. That is why Kissinger (Reference 5) used a case-by-case, structured, application of engineering judgment to arrive at the level flotation benefit estimate, rather than an ARM-like computation based on historical probabilities of recovery. In analyzing the combined effects of level flotation and increased PFD usage, four types of accidents must be considered:

1) Accidents where level flotation alone has little or no chance of preventing the fatalities and PFDs alone would prevent the fatality.

2) Accidents where either level flotation or PFDs alone could have prevented the fatality.

3) Accidents where PFDs have no chance and level flotation alone could have prevented the fatality.

4) Accidents where both PFDs and level flotation are necessary to prevent the fatality.

In comparing the ARM estimates of PFD effectiveness to Reference 5, the following is important:

1) Both studies contain accidents of Type 2, i.e., those where either PFDs or level flotation could have prevented the accident. Thus, there is some "double counting" of benefits if both level flotation and a new PFD regulation were implemented.

2) Neither study contains accidents of Type 4, i.e., those where both level flotation and a new PFD regulation are required to prevent the accident.

Reviewing Reference 5, the following points are important:

1) 47% of the drowning fatalities were not "relevant" to prevention by level flotation due to the fact that one or more intact boats remained in the area after the accident. These were cases of falls overboards or "tossed overboards after a collision" or fire and explosions in which the boat was consumed by fire.

2) Only 36% of the remaining drownings could be saved by level flotation primarily due to the victims drowning prior to being able to return to the boat <u>or</u> electing to strike for shore rather than return to the boat.

Thus, only 19% of the accidents (those preventable by level flotation) are even possible candidates for Accident Type 2 (preventable by level flotation and PFDs), while 34% of the accidents (those for which level flotation was "relevant" but judged unable to prevent due to victim's inability to return to the boat, etc.) are possibly of Type 4. Therefore, there are more accidents where the synergistic effects of level flotation and wearable PFDs might prevent heretofore uncounted fatalities than accidents where we may be double counting. Nevertheless, the effect or level flotation of the calculation of a "conditional" LSI given a level floating boat must be studied. To do so will require both the

use of extensive engineering judgment, and accident data from 1978, which should include model year 1978 boats meeting the level flotation standard as well as model year 1977 boats which chose to comply with the new level flotation regulation.

REFERENCES

1. Doll, T.J., et al., Personal Flotation Devices Research - Phase 1, Wyle Laboratories, July 1976. NTIS No. AD-A037 221/9GA.
2. Keatinge, W.R., Survival in Cold Water, Oxford; Blackwell Scientific, 1969.
3. Hayward, J.S., Thermal Protection Performance of Personel Flotation Devices, Study Performed for Ministry of Transport, Ottawa, Canada, 1976, Unpublished.
4. Cohen, S., R. Giuntini and C. Stiehl, Regulatory Effectiveness Methodology - Phase II Research, First Interim Report, Wyle Laboratories for the U.S. Coast Guard, April 1977.
5. An Analysis of 1974 Fatal Accidents: Predicting the Effectiveness of a Level Flotation Standard, J. R. Kissinger, 1976, Report CG-B-1-76.